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A COMMERCIAL METHOD OF CONTROLLING APPLE SCALD WITH DIPHENYLAMINE EMULSIONS

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Cool storage operators in Australia and New Zealand consider superficial scald to be one of the most serious physiological disorders encountered in long storage of apples. It is entirely a disorder of the cuticle and epidermis, underlying tissues remaining normal until invaded by fungi. The most characteristic symptom in New Zealand† is a series of irregularly shaped blotches coloured light brown at first, but gradually darkening until they become almost black (Fig. 1). Symptoms seldom appear on apples stored for less than four months. Susceptible fruit held in cool store for five to six months usually appears normal until it is removed for sale, then scald develops rapidly during the first few days at room temperature. The cause of scald is still not known.

In 1919 Brooks *et al.* demonstrated that paper wraps treated with various fats and oils greatly reduced scald. Oil-impregnated paper wraps have been used for many years to reduce this form of wastage, but after five months' storage scald develops rapidly in spite of them. An entirely new method of control was discovered by Smock (1955), who showed that diphenylamine (DPA) practically eliminated scald. Padfield (1959) showed that DPA was equally effective on all susceptible New Zealand apple varieties, with the exception of Statesman. Paper wraps impregnated with DPA, or dips in alcohol/water suspensions both gave complete control. Where fruit is packed before storage, treated wraps offer an ideal method of scald prevention, but for storage of loose packed fruit in orchard boxes some other method of treatment is required.

Little is known of the levels of DPA required to protect different varieties of apple. Where levels have been reported, the delay between sampling and treatment was long enough to have allowed significant loss of DPA; some damage to apples caused by treatment with DPA has been noted (Padfield, 1959). The vapour-phase method of Huelin and Kennett (1958) would not be suitable for the bulk treatment of apples in cases.

The present work was undertaken in an attempt to establish a commercially suitable method of applying DPA to apples loose-packed in bushel cases, which would not damage the apples, and by which predictable levels of DPA could be obtained. Information was also sought on the extent of scald protection given by various levels of DPA and on those variables, either of the apple itself or of the method of application, which affect DPA uptake.

* Since resigned.

† The symptoms described here are typical of the disease in New Zealand; they may not apply elsewhere.

METHODS.

Analytical.

All DPA estimations were made on the peel only, since Harvey and Clark (1959) established that little if any DPA penetrates into the flesh of the apple. Sample apples were peeled and extracted with petroleum ether (40–70° C. boiling range, redistilled) within 24 hours of DPA treatment. The bottle containing the peelings covered with petroleum ether was heated on a water bath until the solvent boiled and boiling had continued for about five minutes. The extract was transferred to a volumetric flask, the peelings washed twice with petroleum ether, extract and washings combined and made up to volume. DPA was estimated by the method described by Harvey (1958) except that concentration of the extract was not normally necessary, and colour development was carried out in a separatory funnel with an appropriate aliquot of eluate. Colour measurements were made either with a Hilger " Bio-Chem " absorptiometer using an Ilford 607 spectrum orange filter or with a Beckman spectrophotometer at 590 mμ.

The normal sampling procedure was to take the number of apples, usually one to four, required for obtaining an adequate amount of DPA in the extract. Separate samples were taken from each of the three or four boxes receiving the same treatment. Experimental results are quoted as the mean of these three or four determinations, coefficients of variation being reported where applicable. They were generally of the order of 10–20%.

Untreated apples frequently gave a positive DPA reading of up to 0·2 p.p.m. No correction has been made for this " blank " value in the analytical data.

Since superficial scald and DPA uptake are both surface phenomena, it is more appropriate to express DPA concentrations as γ/cm.^{2} rather than as p.p.m., though the latter figure is suitable for toxicological studies. The surface area of apples was obtained by assuming them to be spheres and applying the surface to volume relationship of a sphere ; apple volume was obtained from weight and density measurements.

In Fig. 2 the concentrations of DPA, expressed as γ/cm.^{2} and p.p.m., on eight Dougherty apples of different weights are plotted against surface area and weight respectively. All the apples had been simultaneously treated with DPA. It is apparent that DPA concentration expressed as p.p.m. is negatively correlated with weight whereas when expressed as γ/cm.^{2} it is independent of surface area.

It may be noted that, for an apple weighing 180 gm. with a volume of 220 c.c., the value of DPA uptake expressed as either p.p.m. or as γ/cm.^{2} is numerically equal. For larger apples the p.p.m. figure becomes progressively smaller than γ/cm.^{2} and conversely for smaller apples.

Preparation of emulsions.

Apples were treated with DPA carried in an oil-water emulsion. The oil used was Shell " Octaro " of the following specification :

Flash point (Pensky-Martens)	Min. 100° F.
Boiling range	145–200° F.
Colour (Saybolt)	Min. 25
Aromatic content	Min. 80% v./v.

To the oil was added 10% v./v. of Shell " Nonidet P.80 ", a spreading agent used in

PLATE I.

Fig. 1.
Severe symptoms of superficial scald on the apple variety Granny Smith.

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the formulation of horticultural sprays. Its presence was to ensure adequate wetting of the apple as well as to assist in the emulsification. The oil solution was made up to a known w./v. % of DPA, usually 10%, and than emulsified with an equal volume of water by passing the oil-water mixture five times through an homogenizer, a Premier Colloid Mill, running at 15,000 r.p.m. with the clearance between stator and rotor set 0·003 in. The concentrated emulsion remained stable for several months.

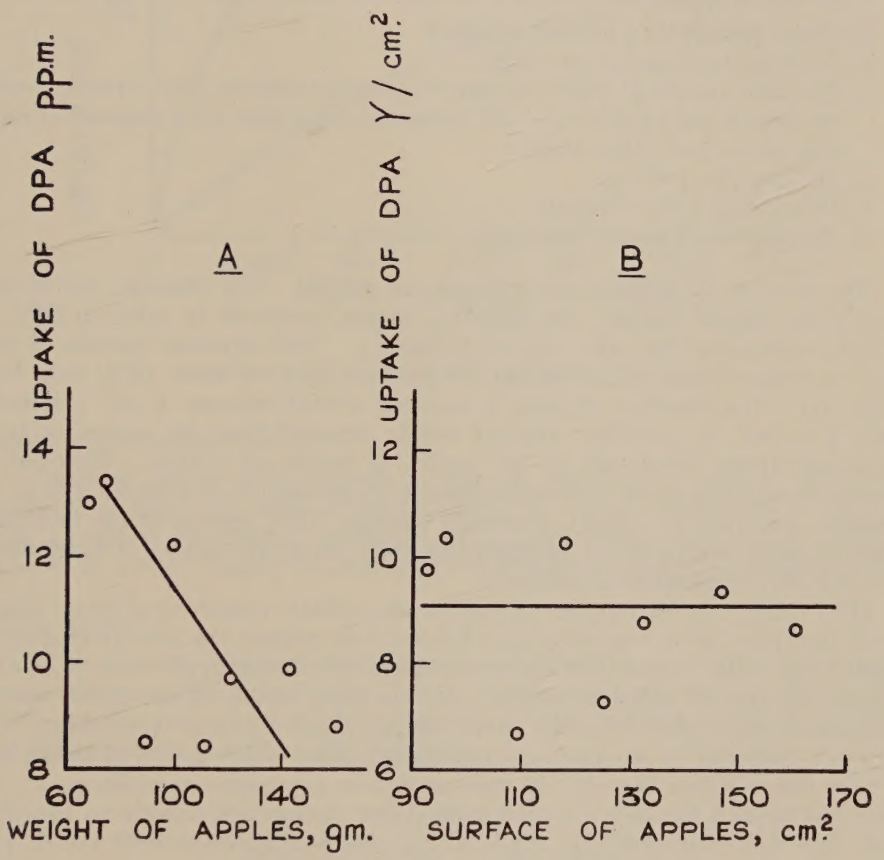

Fig. 2.

Effect of apple size on DPA uptake.

For use, the concentrated emulsion was further diluted with water, usually 1 to 25 to give a nominal 0·2% DPA emulsion, by circulating the mixture through the spray equipment described below. The dilute emulsions remained stable for several days.

This treatment gave emulsions of fairly uniform globule size, most globules being between 1 and 4μ diameter, with very few exceeding 5μ. Without homogenization less uniform emulsions with much larger globules were formed, these coarse

emulsions gradually breaking down into finer emulsions during their passage through the spray equipment. DPA uptake was found to be negatively correlated with globule size ; hence, until fine uniform emulsions were formed, it was not possible to obtain reproducible DPA uptakes with the same spray treatments.

Drench procedure.

Each case of apples, unless otherwise reported, received the following treatment :

1. Water drench for $\frac{1}{2}$ minute or longer.
2. Drainage for $\frac{1}{2}$ minute or longer.
3. Emulsion drench for time necessary to give the required DPA uptake, usually between 1 and 10 minutes. All apples in a case were fully covered by emulsion at the end of this stage.
4. Drainage for $\frac{1}{2}$ minute.
5. Water drench for 1 minute.
6. Drainage for $\frac{1}{2}$ minute or longer.

The duration of steps 1, 2 and 6 was not critical. The drainage period after stage 3 was highly critical. On draining, apples continued to take up DPA for at least a minute at the same rate as in stage 3. With drainage periods of more than 2 minutes apples at the bottom of the case took up more DPA than those at the top. The duration of stage 5 was not critical between $\frac{1}{2}$ and 2 minutes. Below $\frac{1}{2}$ minute the emulsion was not wholly removed from the apples or boxes and brown stains developed on the apples at points of contact. Provided all emulsion was removed by this water drench no damage to the apples due to the treatment was observed after 6–7 months' storage. The purpose of the first water drench (stage 1) was to reduce uptake of emulsion on to the surface of boxes during the subsequent application of emulsion.

DPA emulsions were applied through a pipe system consisting of seven lengths of $\frac{1}{2}$ in. steel pipe, 20 in. long with $\frac{1}{16}$ in. holes at 1 in. centres, the area covered by the drench being rather larger than the cross section of a bushel apple case. Each box of apples was treated within a chamber, the box being supported on runners above a pyramidal bottom which formed a sump holding about 5 gallons of emulsion. The sump was connected to the inlet of a centrifugal pump which delivered about 1,200 g.p.h. of the emulsion through the pipe system at a pressure of 12 lb. p.s.i. The water was applied through a similar pipe system connected directly to the water supply and delivering about 400 g.p.h. at a pressure of approximately 150 lb. p.s.i.

RESULTS.

Variables affecting DPA uptake.

DPA concentration.

A 10% w./v. DPA solution in oil was emulsified with an equal volume of water. Portions of the emulsion were further diluted with water to give DPA emulsions of various nominal concentrations. These emulsions were applied as drenches to samples of Granny Smith and Ballarat apples and the DPA uptakes measured. The results are plotted in Fig. 3.

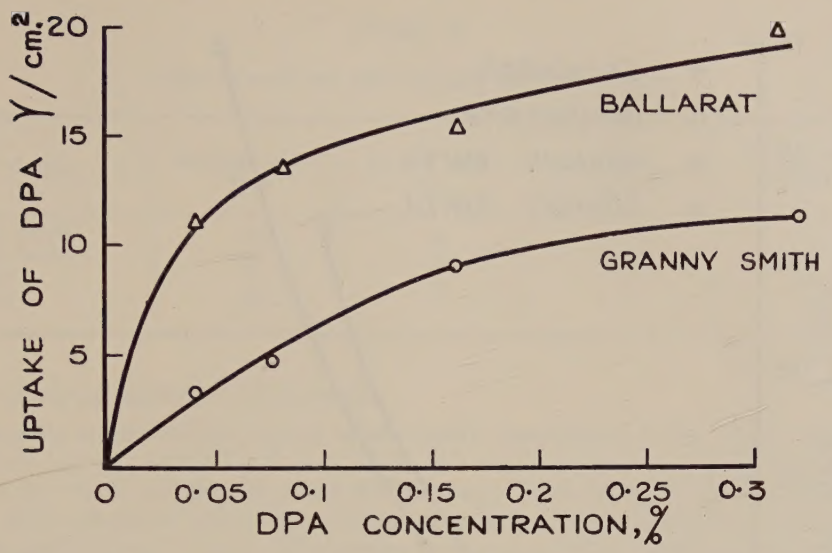

Fig. 3.
Correlation of DPA uptake and emulsion concentration.

Duration of emulsion treatment.

Boxes of apples were treated for various times with nominal 0·2% w./v. emulsions of DPA, all other treatments being the same. DPA uptakes are plotted (Fig. 4) against duration of treatment which includes ½ min. drainage. The two samples of Granny Smith were harvested at different times from different orchards.

Apple variety.

With a 1 min. drench (nominal 0·2% w./v. DPA) and all other treatments the same, DPA uptakes were measured for a number of varieties and are set out in Table I. The two samples of Granny Smith and Ballarat came from different orchards and were picked at different times.

Table I.

Variation of DPA uptake with variety.

Variety	DPA uptake γ/cm.²
Worcester Pearmain ..	14·5
Gravenstein	14·5
Cox's Orange Pippin ..	6·8
Ballarat (1)	4·0
Ballarat (2)	1·6
Dougherty	2·9
Granny Smith (1)	1·0
Granny Smith (2)	0·76

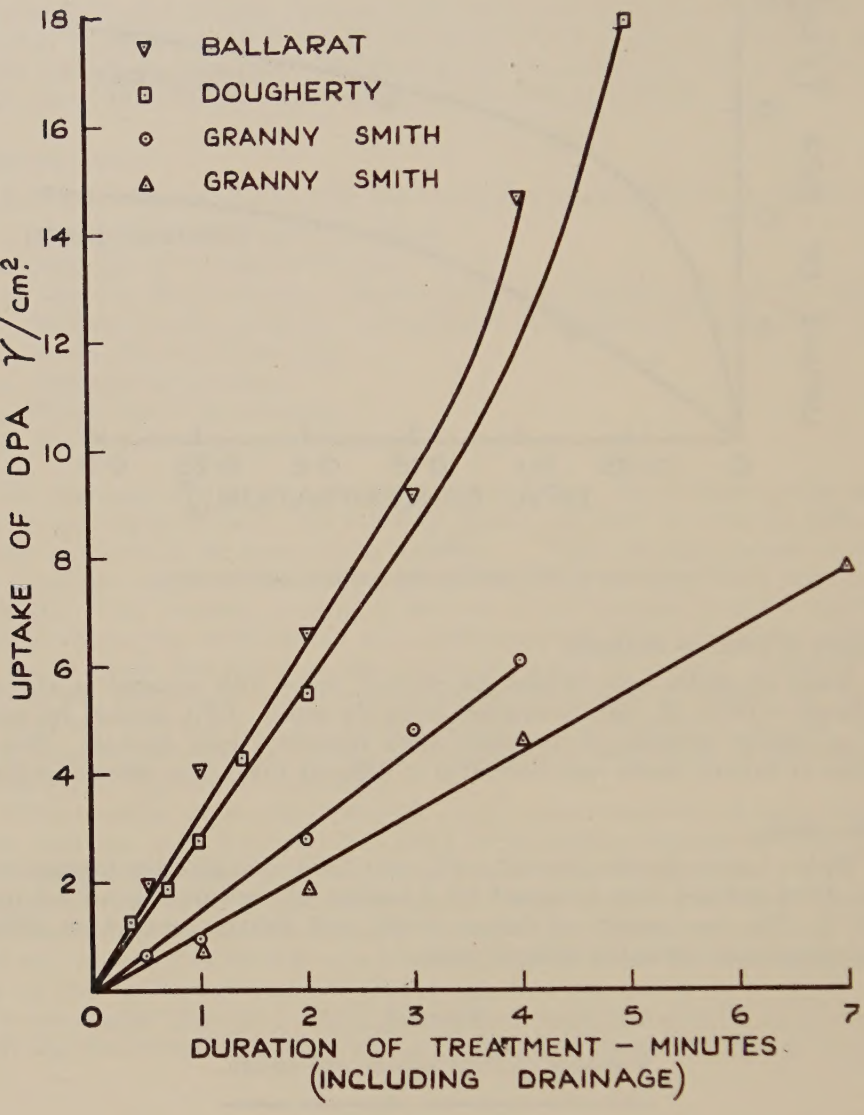

FIG. 4.

Correlation of DPA uptake and duration of spray treatment.

Maturity after picking.

Samples of Granny Smith and Ballarat were stored at room temperature for periods of six and four weeks respectively. One sample of each variety was treated with DPA at the beginning of the storage period and a second sample received the same treatment at the end of storage. Results are set out in Table II.

Table II.

Effect of maturity after picking on DPA uptake.

Variety	Storage period days	Apples tested No.	Mean DPA uptake γ/cm.^{2}	Coefficient of variation %
Granny Smith ..	5	6	2·5	9
Granny Smith ..	47	9	9·1	12
Ballarat	4	10	7·7	10
Ballarat	28	8	13·9	5

Effect of wiping apples on DPA uptake.

Apples are frequently stored while visibly contaminated with spray residues. One such case of Granny Smith was taken, half of the apples were gently wiped clean with a dry cloth and the other half left unclean. Both groups were then given the same DPA treatment and DPA uptakes measured on eight apples from each group. Wiped apples showed a mean DPA uptake of 9·4 γ/cm.^{2} with a coefficient of variation of 8%, whereas the unwiped apples had a DPA uptake of 6·2 γ/cm.^{2} and coefficient of variation of 24%.

Loss of DPA.

In emulsions. During the drenching process (stage 3, p. 76) DPA concentration in emulsions gradually fell as a result of uptake of DPA by apples and dilution of the emulsion. This is because water is added to the emulsion sump from the first water wash but emulsion is removed from it. Concentrations of DPA in emulsions before and after treating a number of boxes are shown in Table III. The initial volume of emulsion was four gallons in each case.

Table III.

Loss of DPA from emulsions.

No. of boxes treated	DPA concentrations	
	Before treatment %	After treatment %
8	0·15	0·13
8	0·16	0·14
12	0·16	0·12
16	0·16	0·10

On apples during storage. In Table IV are set out the initial and final DPA concentrations on three varieties of apple held in cold storage. The results, mainly of toxicological interest, are expressed as p.p.m. Figures below 0·5 p.p.m. have little significance since untreated apples assay at varying amounts up to 0·2 p.p.m.

TABLE IV.

Loss of DPA from apples during storage.

Variety	Storage period days	DPA concentrations		
		Before storage		After storage
		p.p.m.	Coefficient of variation %	p.p.m.
Granny Smith ..	199	15·6	18	1·0
		11·0	22	0·9
		4·5	11	0·4
		1·8	14	0·3
Ballarat	207	6·7	11	0·5
		4·6	16	0·3
		1·4	22	0·2
Dougherty	172	12·4	9	1·1
		4·8	8	0·5
		1·4	11	0·3

By measuring DPA concentration at intervals during storage the rate of loss was obtained for a sample of Dougherty apples. In Fig. 5, log.DPA concentration has been plotted against storage time for four samples of different initial concentrations.

DPA UPTAKE AND SCALD PROTECTION.

Of a sample of Granny Smith apples picked on the same day from the same orchard, one group (A) was held at ambient temperature for five days before treating with DPA, the other group (C) was held in cold store at about 33° F. for five days before treatment. Both groups were given various drench treatments as set out in Table V. Each treatment was given to at least four bushel cases of apples, which were then sampled for estimating DPA uptake. The apples were placed in cold store and held at 33° F. for 27 weeks, removed from cold store and held at ambient temperature for a further period of ten days. All cases of apples were then examined for superficial scald, the severity of scald being differentiated between slight and severe according as the area affected was less or more than about 2 sq. cm., an arbitrary division based on trade practice in separating saleable from waste fruit.

"Shadow scald" is the name given to a slight darkening of the skin, quite distinct from the normal deep brown of superficial scald. This symptom has not been reported previously from New Zealand, and it is not known whether it is a normal component of the scald complex. In most scald experiments prior to the introduction of DPA, symptoms were severe in all treatments, and it is probable that any faint changes in skin colour were masked by the dark brown of typical superficial scald. Areas affected by shadow scald were small and the colour change so slight as to be negligible commercially. As this symptom appeared on both treated and untreated apples it was considered to be a form of scald rather than injury induced by treatment.

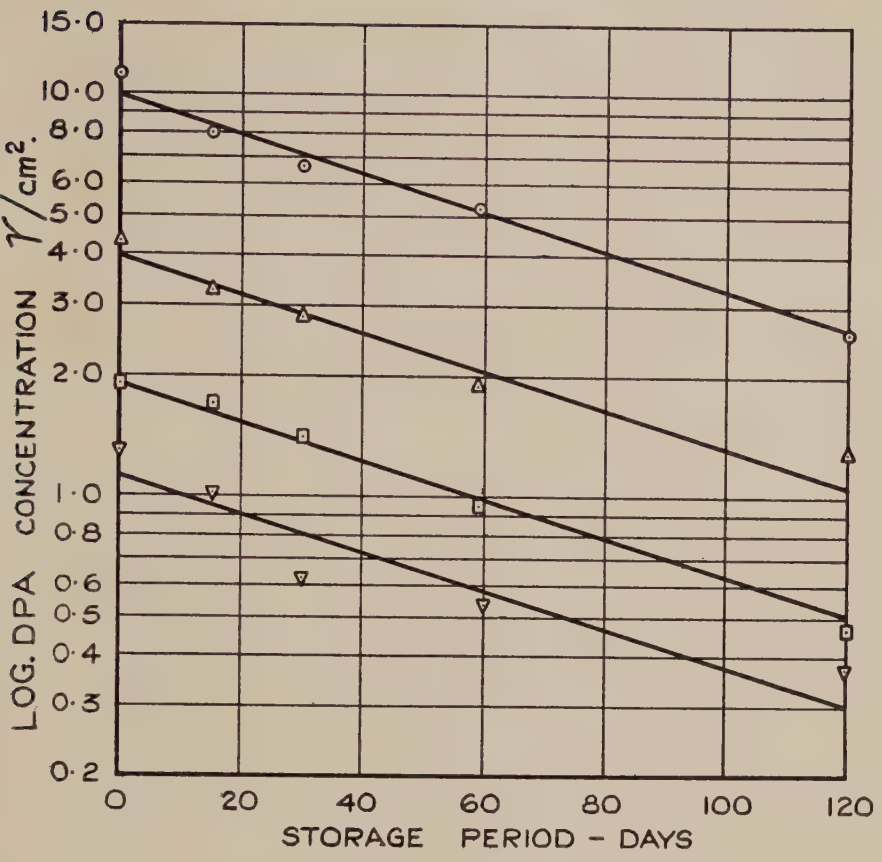

Fig. 5.
Decay of DPA in storage.

The percentage of each type of scald found for the different treatments is recorded in Table V, and from the data an arbitrary score for scald incidence has been calculated for each treatment according to the following relation:

$$\text{Scald incidence score} = \frac{(\%\ \text{shadow scald}) \times 1 + (\%\ \text{slight scald}) \times 2 + (\%\ \text{severe scald}) \times 3}{3}$$

The score for scald incidence thus lies between zero when no scald has developed and 100 for a sample with every apple showing severe scald.

DISCUSSION.

The method of DPA application described could be readily adapted to large-scale commercial application. A convenient method would be for boxes of apples to be placed on an endless moving belt which would carry them through an appropriate

TABLE V.

DPA uptake and incidence of scald.

Sample reference	Pre-treatment storage	Spray treatment				Superficial scald			
		Nominal DPA strength of emulsion %w.v.	Duration of drench treatment mins.	DPA uptake γ/cm.²	Coefficient of variation %	Slight %	Severe %	Shadow scald %	Scald incidence score* %
A1	Ambient	0·2	8	11·5	22	0	0	0	0
A2	,,	0·2	4	4·6	11	0	0	3	1
A3	,,	0·2	2	1·9	14	0	0·5	5·75	2
A4	,,	0·2	1	0·76	18	7	1·5	2·25	7
A5	,,	Nil	8	—	—	38·5	2·5	3	29
A6	,,	No treatment	—	—	—	28·75	53·25	2·75	73
C1	Cold store	0·2	10·8	16·4	18	0	0·25	3·25	1
C2	,,	0·2	5·4	4·0	20	0·25	0	7·25	3
C3	,,	0·2	2·0	1·5	16	6·5	1·25	8·75	8
C4	,,	0·2	1·35	0·42	11	40·25	15	4·25	43
C5	,,	Nil	10·8	—	—	44·0	4·5	4·5	35
C6	,,	Nil	5·4	—	—	28	61·5	4·25	81
C7	,,	No treatment	—	—	—	10·25	87·5	0·75	95

* For definition, see text.

series of washing, treatment, and drainage sections in a suitable tunnel, the time of treatment in any section being determined by its length and the speed of the belt.

Though DPA uptake is not proportional to the DPA concentration in the emulsion (Fig. 3), it is almost directly proportional to the duration of emulsion drench treatment, which thoroughly wets the surface, at least up to 6γ/cm.^{2}, as is shown in Fig. 4. Above this level DPA uptake increases more rapidly than the duration of the drench. There were indications that with these longer drench times permanent changes to the apple's wax layer were occurring ; for example, half an hour's treatment was sufficient to destroy the protective action of the wax to penetration of oxygen, with the result that browning of the apple tissue developed.

Variables of the apple itself, such as variety, maturity, and waxiness of the surface, greatly influence the DPA uptake for a given treatment. Thus, from Table I, DPA uptake varies by more than tenfold for different varieties. Storing apples at room temperature before treatment increased DPA uptake by about 100% after four weeks—see Table II. During this storage period there is a noticeable increase in the greasiness of the apple's surface to the touch and hence an expected increased absorption of the oil carrying DPA from the emulsion.

The level of DPA uptake from a particular treatment appears to be negatively correlated with scald susceptibility. Thus, in Table I, Granny Smith shows the lowest DPA uptake and it is rated by Padfield (1954) as the New Zealand variety most susceptible to scald. Worcester Pearmain and Gravenstein, not listed by this author as susceptible, have exceptionally high DPA uptakes, while Ballarat and Dougherty occupy an intermediate position in both scald susceptibility and DPA uptake. Moreover, delay between harvesting and cold storage has been shown here both to increase DPA uptake and to reduce scald incidence.

From Fig. 5 it is seen that DPA disappears from the surface of an apple at an exponential rate. The rate of loss varied with different varieties ; thus, under similar storage conditions, it was more than twice as great on Ballarat as on Dougherty. It is thus difficult to attribute a physical cause, such as sublimation, to this loss and a more probable explanation of the exponential rate would be a monomolecular chemical reaction involving DPA. In any case, it should be noted that the rates of loss are sufficiently high, at the higher levels, to require DPA estimations to be made within a very few days of treatment if substantial errors are to be avoided.

From Table V it is clear that the initial DPA concentration on the apple's surface is positively correlated with the extent of the scald protection during storage. However, the minor differences in storage for a few days before treatment between the (A) and (C) series were sufficient to cause notable differences in scald protection. At all DPA levels investigated, and with the untreated controls, the (C) series show a greater incidence of scald than the (A) series. This confirms Padfield's (1949) work with the variety Granny Smith, and shows that further information is required before it will be possible to define the DPA treatment required to prevent scald under all conditions.

Emulsion alone, without DPA, afforded some protection against scald, as would be expected with a variety known to respond to oiled wraps.

Diphenylamine has not yet been approved by the health authorities of any country for use on fruit intended for human consumption. Toxicity trials are in progress in the United States of America, but final results are not expected before the middle of 1961.

SUMMARY.

1. A method is described for the protection of apples, loose-packed in bushel cases, from superficial scald by drenching them with oil-water emulsions containing diphenylamine (DPA).

2. By varying the duration of drench treatment predictable levels of DPA uptake could be obtained.

3. Different varieties of apple differed by more than tenfold in DPA uptake for the same treatment.

4. The rate of loss of DPA at any time from the surface of the apple was proportional to DPA concentration at that time.

5. With Granny Smith apples after six months' cold storage, 100% protection from scald was obtained in one instance ; in others the extent of scald protection was related to the level of DPA applied.

6. Slight scald protection was obtained with similar oil-water emulsions containing no DPA.

7. Apples held at ambient temperature for six days between harvesting and treatment were less susceptible to scald than those held in cold store for a similar time.

8. A possible correlation between scald susceptibility and DPA uptake for a given treatment is noted.

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STORAGE OF TOMATOES IN ARTIFICIAL ATMOSPHERES USING THE CALCIUM HYDROXIDE ABSORPTION METHOD

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THE influence of ten different gas mixtures on tomatoes stored at 8·5° C., 12° C. and 15° C. was investigated by Kidd and West (1932b). They reported that an atmosphere containing 5% CO_2 and 5% O_2 was the most effective, among those investigated, in retarding the ripening processes and fungal growth. They also observed that tomatoes stored at the lowest temperature, 8·5° C., were subject to an injury which " manifests itself by a decrease in the power of resistance to fungal attack ". Furlong (1946) obtained similar results with two gas mixtures containing 5% O_2 with 5 and 10% CO_2.

In order to maintain the desired gas concentration the above workers removed the excess CO_2 by scrubbing the storage atmosphere once daily with an alkaline solution, a method first introduced by Kidd and West (1932a). This method as currently used is discontinuous and tends to provide fluctuating gas concentrations and requires constant attention.

Eaves (1959) developed a dry scrubber, based on the diffusion of the atmosphere over Ca $(OH)_2$, for commercial controlled-atmosphere storages. He also used it on a laboratory scale in preliminary experiments on pear storage (Eaves, 1958).

The object of the present study was twofold, (1) to assess the effectiveness of the absorption method and its influence, if any, on the quality of stored tomatoes, and (2) to establish the optimum storage conditions for field-grown tomatoes.

Materials and methods.

In this study portable storage cabinets, each capable of holding 3 standard bushel boxes (30×14×21 in.), were made gas-tight with double-sided aluminium foil (Fig. 1, A). The joints were sealed with vaseline and a plastic window 6×6 in. (B) inserted in the top of each cabinet. A CO_2 absorption chamber (12×8×7 in.) (C) made of galvanized iron was bolted and sealed to the end of each cabinet. To control the rate of atmospheric diffusion a 1·5 in. bore gate valve (D) was inserted between the cabinet and the absorption chamber. The stem of the valve passed through the wall of the absorption chamber to provide external control of the aperture (E). The CO_2 absorbent, consisting of 1·4 kg. of $Ca(OH)_2$, was placed in sealed paper bags (F) which could if necessary be quickly replaced by a fresh charge. These bags were inserted through a sliding panel (G) at the front end of the chamber. This panel was set in grooves filled with mastic compound. The O_2 level was controlled by a series of 12 vents 0·1 inches in diameter (H) in the top of the cabinet.*

* Subsequent work has shown that a $\frac{1}{2}$ inch stop valve inserted into the wall of the scrubbing chamber gives more efficient control of the O_2 concentration than the oxygen vents.

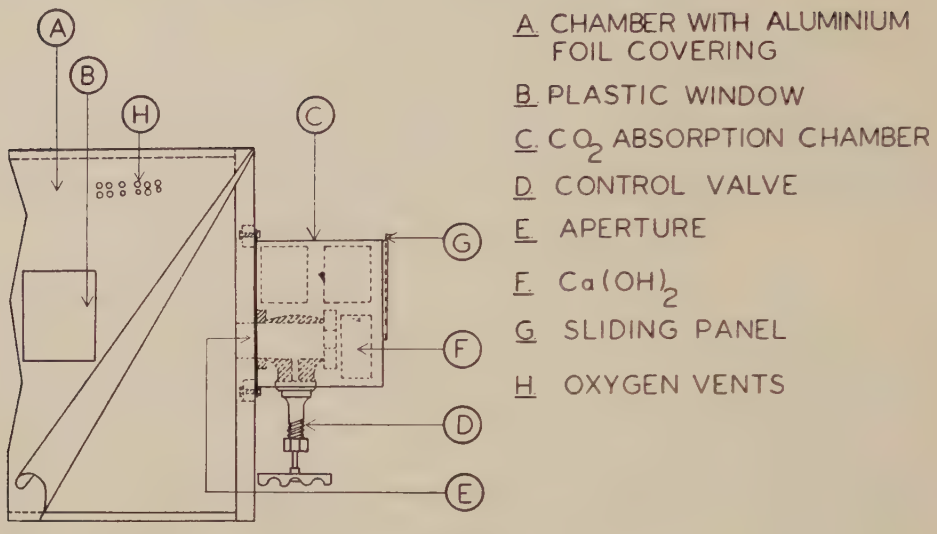

FIG. 1.
Gas storage cabinet and carbon dioxide absorber.

The bushel boxes used with the cabinets were equipped with movable dividers so that four separate layers of approximately 35 fruits were held in each, thus giving a total of 420 tomatoes in each cabinet.

The desired initial storage temperatures, namely 4·4° C. and 12·7° C., were obtained by placing the gas storage cabinets in controlled temperature rooms equipped with fans. All the fruit used was subjected to a 24-hour conditioning period in air at the appropriate temperature before being placed in the cabinets.

Sound tomatoes at the mature green stage of ripening were used throughout. These were carefully selected and placed in paper wraps before storage.

After the storage period each layer of fruit was examined for ripeness. This was estimated as the percentage of tomatoes showing red, red-green and green colour. A ripening index was calculated as the summation of the percentage of fruit with red colour ×3, red-green ×2 and green ×1, and the total divided by 3. Thus a sample of full-ripe fruit received an index of 100. Observations on fungal decay and flavour were also recorded.

Gas concentrations were measured daily with a modified Orsat gas analysis apparatus.

RESULTS AND DISCUSSION.

Experiment I.

Tomatoes of the variety Scotian were picked on 17th August and samples stored in 8 different gas mixtures, plus an air control, for 21 days at 12·7° C. (Fig. 2). Thereafter one box from each cabinet was held in air for 1 week at 4·4° C., 12·7° C. and 21·0° C.

It will be seen in Fig. 2 that, apart from minor fluctuations, the desired concentrations of CO_2 and O_2 were satisfactorily maintained. The reduction in the level of O_2 from 21·0% to 2·5% took approximately 5 days. This time lag could have

been reduced by a corresponding reduction in the free air space in the cabinet. The free space, however, must be considered in relation to the gas-sampling procedure. With a macro method, as used here, it is necessary to withdraw 400-500 ml. of gas in order to obtain a true sample and, in so doing, a partial vacuum is formed if there

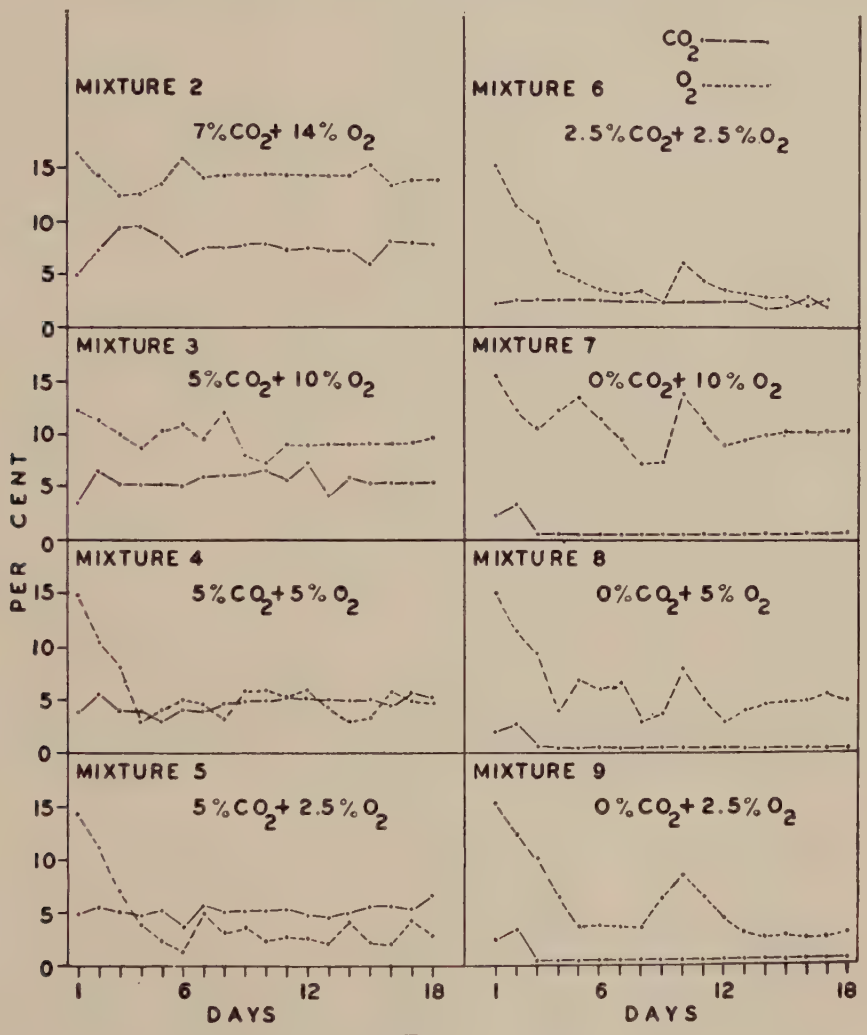

Fig. 2.

Gas concentrations with calcium hydroxide absorption; tomato storage at 12·7° C.

is no air intake. This situation existed, for example, during the O_2 reduction period referred to above.

It was found that O_2 control could be best achieved by closing all vents, allowing the O_2 level to fall below that required and then successively opening the vents. All vents were required to maintain 10·0% O_2 whereas only two were necessary for

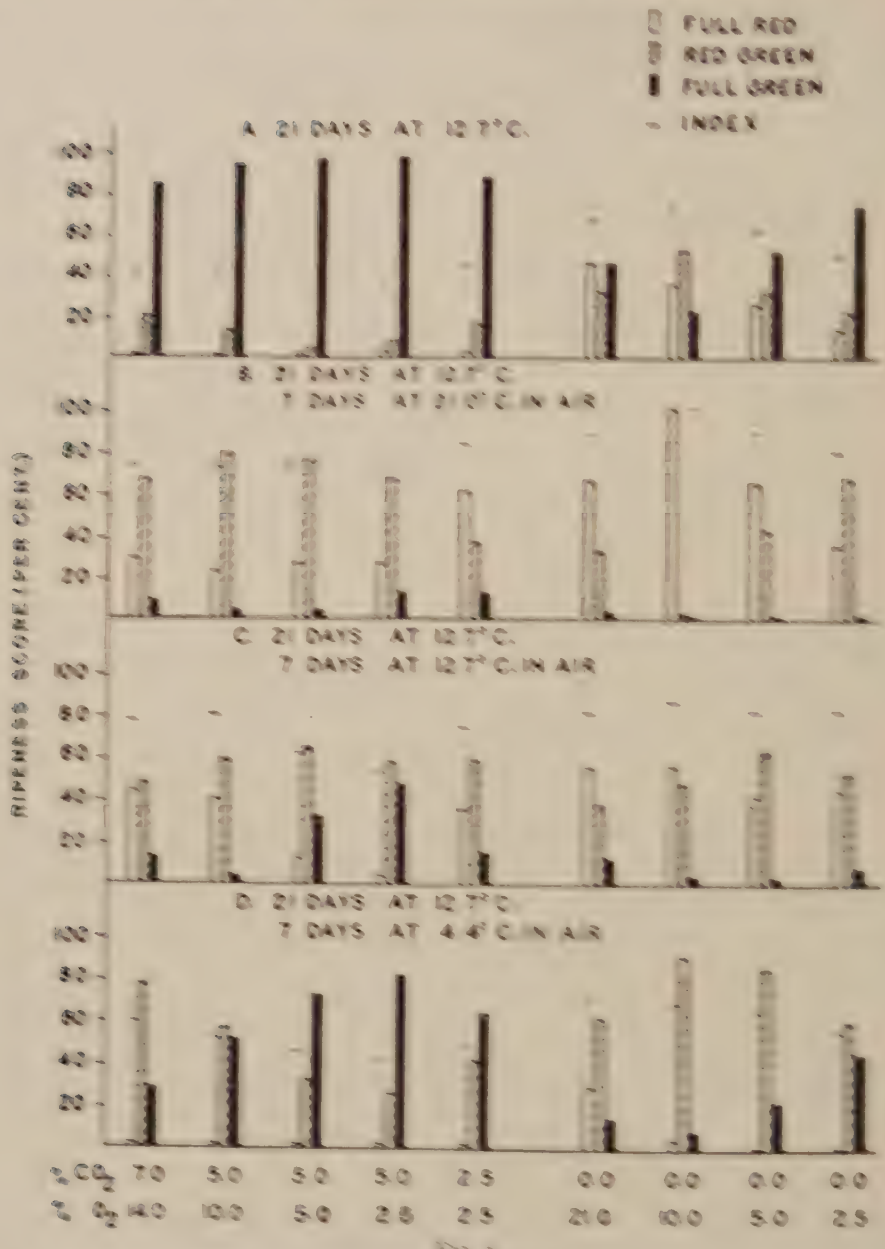
FULL RED
RED GREEN
FULL GREEN
INDEX
A 21 DAYS AT 12.7°C.
B 21 DAYS AT 12.7°C.
7 DAYS AT 21.0°C. IN AIR
C 21 DAYS AT 12.7°C.
7 DAYS AT 12.7°C. IN AIR
D 21 DAYS AT 12.7°C.
7 DAYS AT 4.4°C. IN AIR
RIPENESS SCORE (PER CENT.)
% CO_2 7.0 5.0 5.0 5.0 2.5 0.0 0.0 0.0 0.0
% O_2 14.0 10.0 5.0 2.5 2.5 21.0 10.0 5.0 2.5

FIG. 1.

Influence of artificial atmospheres on the ripening of tomatoes stored at 12.7°C.

2.5%. The control of the CO_2 level was accomplished by allowing the gas to accumulate above the desired concentration before opening the diffusion valve. A constant equilibrium of 2.5% was obtained with the valve fully open and one of 5% by opening

the valve 0·25 inches or one full turn. To maintain the minimum CO_2 level, which approximated to 0·8%, it was necessary to insert an additional 1·4 kg. of $Ca(OH)_2$ into the cabinet 2 days after the beginning of the experiment, as the size of valve was inadequate. Once the required gas concentrations were obtained, the continuous absorption of CO_2 gave stability to the atmospheric conditions.

After 3 weeks it was found that the absorbents associated with 2·5 and 5% CO_2 had increased in weight by 25·0 and 22·8% respectively. The heat evolved in the absorption process was rapidly dissipated when the chamber was cooled by refrigerated air, as in this experiment. The volatile gases that emanate from stored fruit, which affect the ripening processes, are not removed by the absorption method as they are in the continuous gas flow procedure (Kidd and West, 1932a). For this reason the results should be more comparable to those obtaining in commercial practice.

The effects of the gas mixtures on the fruit ripening process are shown in Fig. 3. The delay associated with the presence of CO_2 is clearly shown. Those fruits examined immediately after removal from the atmospheres containing 5% CO_2 and decreasing levels of O_2, namely 10·0, 5·0 and 2·5%, had ripening indices of 37, 36 and 35 respectively (Fig. 3, A). These uniform values mask the O_2 effect. On subsequent ripening in air at 12·7° C., however, the indices advanced to 78, 60 and 52 (Fig. 3, C), showing that O_2 levels also affect the rate of ripening. Fruit stored without CO_2 but in the presence of the same decreasing levels of O_2 showed the oxygen effect on removal from the artificial atmospheres. This is demonstrated by the high percentage of green tomatoes at the 2·5% level of O_2 (Fig. 3, A).

The dominant influence of CO_2 is exemplified by a comparison of the results obtained with 5% and 2·5% concentrations of this gas with a fixed O_2 level of 2·5%. It will be seen in Fig. 3, B, that there were twice as many ripe fruits in the samples stored in 2·5% CO_2.

The development of fungal rot was influenced by the various gas mixtures, as shown in Fig. 4, with the least wastage occurring after 3 weeks in an atmosphere containing 5% CO_2 and 5% O_2. This confirms the findings of Kidd and West

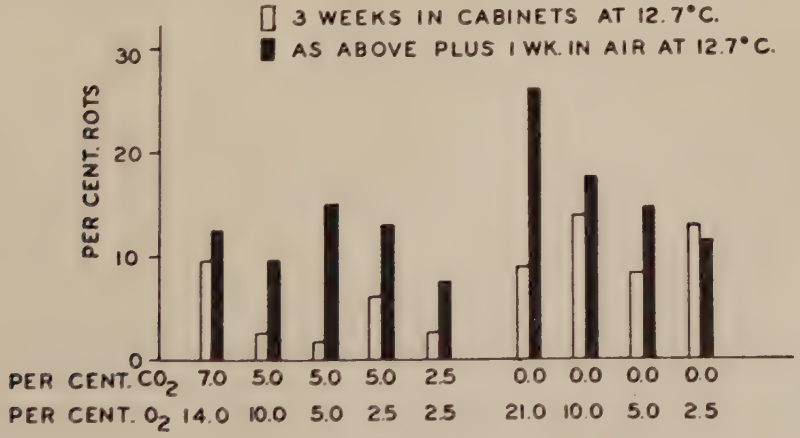
3 WEEKS IN CABINETS AT 12.7°C.
AS ABOVE PLUS 1 WK. IN AIR AT 12.7°C.
PER CENT. ROTS
30
20
10
0
PER CENT. CO2 7.0 5.0 5.0 5.0 2.5 0.0 0.0 0.0 0.0
PER CENT. O2 14.0 10.0 5.0 2.5 2.5 21.0 10.0 5.0 2.5

Fig. 4.

Influence of artificial atmospheres on fungal rot development on tomatoes stored at 12·7° C.

(1932b). On subsequent holding in air at 12·7° C. and 21° C. the 2·5% CO_2 and 2·5% O_2 mixture proved the most effective. With the exception of the wastage found immediately after removal from the 7% CO_2 and 1·4% O_2 mixture, there was a general reduction associated with the presence of CO_2. In this connexion Kidd and West (1932b) found that a concentration of 10% CO_2 resulted in greater wastage than that found at the 5% level. It is interesting to note that the fungal rotting of fruit stored in the absence of CO_2 and subsequently held in air for 1 week decreased progressively with a reduction in the O_2 content of the storage atmosphere.

The interrelationship between rates of ripening and fungal decay is not only important physiologically but also has practical implications. Both in air and in an atmosphere containing 5% CO_2 and 2·5% O_2 fungal decay proceeded at a much faster pace than did ripening. The increases in wastage, when the fruit was held at 12·7° C. during the week following removal from storage, were 206 and 123% for air and the artificial atmosphere respectively, whereas the corresponding increases for the ripening indices were only 28 and 49%.

An examination was made of 20 fruits from each sample stored for 3 weeks in artificial atmospheres and 3 weeks in air at 12·7° C. and then placed at 21·0° C. for the final week. All fruits with the exception of those stored in 5% CO_2 and 2·5% O_2 were fully ripened. Fruits in air and in 0% CO_2 plus 10% O_2 were completely rotted. The flavour of the other samples was uniformly good and there was no evidence of internal or external injury.

Experiments II and III.

In Experiment II tomatoes of the variety Quebec were picked on 22nd September, stored in air at 21-22° C. for 3 days, conditioned, and then stored in an atmosphere containing 5% CO_2 and 2·5% O_2. The fruits, in nine cabinets, were subjected to the following temperature treatments:

(*a*) 4, 8 and 12 weeks at 12·7° C. (3 cabinets).
(*b*) 3 weeks at 12·7° C. and 3, 6 and 9 weeks at 4·4° C. (3 cabinets).
(*c*) 1, 3 and 4 weeks at 4·4° C., then removed to 12·7° C. (3 cabinets).

In Experiment III fruit of the same variety was picked on 2nd October and samples stored immediately after conditioning in 5% CO_2 and 2·5% O_2 for 4, 8 and 12 weeks at 12·7° C. (3 cabinets).

After completion of the storage periods samples of fruit were held at 21·0° C. in air for 1 week.

It should be noted that the fruits used in these experiments were picked much later than those in Experiment I. They had been subjected to night field temperatures ranging between 2·0° C. and 13·0° C. Furthermore the selection of sound marketable tomatoes was considerably more difficult because of a much higher incidence of disease in the field.

As in Experiment I there was a marked retardation of ripening and rot development in the gas mixture but this effect was considerably vitiated by delayed storage in air (Table I). The ripening indices in Experiment III for fruit stored in 5% CO_2 and 2·5% O_2 and in air after 4 weeks were 48 and 78 respectively. These results correspond closely with the calculated indices based on studies by Furlong (1946) which indicate an index of 37 for tomatoes in 5% CO_2 and 5% O_2 and 84 in air after the same storage period.

After 4 and 8 weeks twice as many rots were found in the control fruit as in the treated samples (Table I). The incidence of *Alternaria tenuis* (15 to 25%) in the controls at 12·7° C. confirmed that chilling injury had occurred in the field and substantiated similar observations made by McColloch and Worthington (1952).

Table I.

Ripening and fungal wastage in tomatoes stored in 5·0% CO_2 and 2·5% O_2 at 12·7° C.

Storage period (weeks)	Expt. IIa, harvested 22nd Sept. Delayed storage				Expt. III, harvested 2nd Oct. Immediate storage			
	5·0%CO_2+2·5%O_2		Air		5·0%CO_2+2·5%O_2		Air	
	Ripening index	% rots	Ripening index	% rots	Ripening index	% rots	Ripening index	% rots
4	47	20·5	100	40·0	38	7·0	78	22·6
8	41	50·0	100	100·0	43	49·4	100	100·0
12	43	90·0	Discarded		50	73·0	Discarded	

The failure of tomatoes to ripen satisfactorily after a storage period in excess of 8 days at 4·4° C. (Wright *et al.*, 1931) and the lowered resistance to fungal decay was investigated by preconditioning at 12·7° C. in 5·0% CO_2 and 2·5% O_2 (Experiment IIb).

No improvement was obtained in storage quality by this regime and none of the fruits ripened satisfactorily when placed as 21° C. for 1 week following the treatments shown in Table II. Furthermore the fruit assumed a pebbly appearance and developed internal browning.

Table II.

Influence on tomatoes of storage at 12·7° C. in 5·0% CO_2 and 2·5% O_2 for 3 weeks and transferred at 4·4° C. for 3, 6 and 9 weeks.

Low temp. storage period at 4·4° C. (weeks)	Storage period of 3 weeks at 12·7° C.			
	5·0% CO_2+2·5% O_2		Air	
	Ripening index	% rots	Ripening index	% rots
3	44	58·4	100	91·0
6	44	100·0	Discarded	
9	40	100·0	Discarded	

Experiment IIc constituted a reversal of IIb in that the tomatoes were initially held at 4·4° C. in the gas mixture for 1, 3 and 4 weeks. The cabinets were then moved to 12·7° C. and opened for examination after a total storage period of 9 weeks. All samples were found to be green, with 95 to 100% fungal rots. A sample of 25 sound fruits from each cabinet was held at 21·0° C. Those stored for 1 week at 4·4° C. ripened satisfactorily and developed 3% wastage but the remainder failed to ripen. As was expected, the temperature changes resulted in considerable condensation within the cabinets and this presumably encouraged the development of fungal rotting.

The dominant organisms isolated from the tomatoes of Experiments II and III were as follows: *Phoma destructiva* Plowr., *Alternaria tenuis* Nees, *Botrytis cinerea* Pers. and *Fusarium* spp. Organisms of lesser importance were: *Colletotrichum atramentarium* (Berk. and Br.) Taubenh., *Alternaria solani* E. and M. (Jones and Grout), *Penicillium* sp., *Pullularia pullalans*, *Aspergillus* sp., *Mucor* sp., mycelia sterilia and bacteria.

SUMMARY.

A simplified method for the maintenance of artificial atmospheres in storage cabinets under laboratory conditions and its use in tomato storage studies is described.

Eight different atmospheres containing various concentrations of CO_2 and O_2 were used. The results showed that CO_2 was the dominant gas in the retardation of ripening and tended to mask the effect of reduced O_2 levels. Fungal wastage was reduced in the presence of all levels of CO_2, with the exception of that observed in the fruit stored at the 7% level and examined immediately after removal from the gas mixture. The delaying influence of reduced concentrations of O_2 was noted after removal to air.

Best results from the standpoint of ripening were obtained with a gas mixture containing 5% CO_2 and 2·5% O_2 during a storage period of 12 weeks at 12·7° C. A gas mixture of 2·5% CO_2 and 2·5% O_2 was associated with the minimum development of fungal decay, which was found to be the major limitation to the prolonged storage of tomatoes.

The dominant fungal organisms were *Phoma destructiva*, *Alternaria tenuis*, *Botrytis cinerea* and *Fusarium* spp.

ACKNOWLEDGMENTS.

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POST-HARVEST DEFOLIATION OF STRAWBERRY PLANTATIONS

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POST-HARVEST removal of leaves, either by burning them off together with the straw residue or by mowing-off, has for long been recognized as a useful cultural practice in the management of strawberry plantations. Wilson and Rogers (1954) at East Malling obtained an increase in crop in the year following defoliation.

In Scotland it is the practice to cut back the plants along both sides of the rows after harvest, and where this is done ruthlessly a partial defoliation is accomplished which may be beneficial. Occasionally complete mechanical defoliation is carried out, but for climatic reasons burning-off is not usually possible.

In the strawberry the fruit trusses which produce the following year's crop are initiated in the autumn, from about the end of August to early September in Scotland (Robertson and Wood, 1954). Some varieties may also initiate flowers in June, July and early August, but these trusses emerge during the autumn and fail to survive the winter, although in favourable circumstances they may produce an autumn crop of fruit. Overwintering trusses are protected within the bud and emerge and flower in the following spring. The crop in Scotland is picked during July. The present experiments show that the number of trusses formed during autumn—that is, after about mid-August—is increased by post-harvest defoliation, with a consequent increase in fruit yield in the following summer.

Materials and methods.

All the defoliation experiments were carried out on plantations at Mylnefield which had originally been established for other purposes. Nevertheless, except in a few instances, statistically acceptable designs were possible. Plants were spaced 18 in. apart in rows 3 ft. apart, all runners being removed in the course of cultivation.

Defoliation was done after the first crop in Experiments 1, 3, 4, 5 and 9; after the second crop in Experiments 1a, 2, 6 and 8 ; and after the third crop in Experiments 6a, 7 and 8a. The leaves were cut, either by scythe or by hand shears, close to the crown, so that only emerging leaves remained. The cut foliage, together with any straw residue, was then raked off. Control plots were left intact and received the customary post-harvest cultivations, in which runners were removed and the straw was cleared from between the rows.

The varieties Redgauntlet, Talisman and, in the earlier years, Auchincruive Climax were studied most extensively. A number of unnamed seedlings, also raised by R. D. Reid, were used in some of the experiments, so that, although a large number of different clones were tested, many of them were in some measure related to one another.

The plantations were managed according to good commercial practice. Manure and fertilizer treatments were not always the same in the various experiments,

TABLE I.

Yields of sound fruit and numbers of fruit trusses on defoliated and control plots of strawberry.

Expt. no.	Variety	Date of defoliation	Yield of sound fruit in oz. per plant				Number of trusses per plant			
			Uncut control	De-foliated	Increase over control	Least sig. increase*	Uncut control	De-foliated	Increase over control	Least sig. increase*
1	Climax	12th Aug. '53	5·1	12·1	7·0	—	6·9	21·9	15·0	—
1a	Climax	Mid-Sept. '54	3·9	4·1	0·2	—	15·9	16·4	0·5	—
2	Climax	Mid-Sept. '54	33·2	28·1	−5·1	—	—	—	—	—
3	Talisman	27th July '56	15·4	18·3	2·9	N.S.	—	—	—	—
		15th Aug. '56	15·4	15·1	−0·3	N.S.	—	—	—	—
4	Talisman	2nd Aug. '57	4·5	23·2	18·7	2·85	7·0	27·4	20·4	1·73
	Redgauntlet	2nd Aug. '57	9·2	29·3	20·1	2·85	5·9	16·2	10·3	1·73
	LR19†	2nd Aug. '57	9·5	17·7	8·2	2·85	24·6	28·4	3·8	1·73
	5V322	2nd Aug. '57	3·7	9·2	5·5	2·85	12·1	17·0	4·9	1·73
	5V91	2nd Aug. '57	3·5	15·1	11·6	2·85	7·1	19·8	12·7	1·73
5	22 unnamed seedlings	2nd Aug. '57	5·8	11·5	5·7	—	—	—	—	—

* 2 × standard error of the mean; N.S., not significant. The designs of Experiments 1, 1a, 2 and 5 were not suitable for statistical analysis.

† LR19, 5V322 and 5V91 were unnamed but selected seedlings. LR19 was released to local commerce.

however, and this may partly account for differences of yield from one experiment to another.

The fruit was weighed as either sound and marketable or damaged and unmarketable. The latter included fruit damaged by birds or infected by mildew or by *Botrytis cinerea*, the last of which caused heavy losses of fruit in some seasons.

EXPERIMENTAL RESULTS.

Table I gives the results for the earlier experiments. With one exception, defoliation in August increased the yield of marketable fruit, sometimes to double or treble and in one instance to more than five times the yield of the undefoliated plots. When defoliation was delayed until mid-September the yield was either depressed (Experiment 2) or little affected (Experiment 1a) by the treatment. In Experiment 3, which gave no significant differences, the plants were severely infested with aphids which damaged the emerging inflorescences during spring. This, by depressing the yield, is thought to have suppressed any possible advantage from defoliation, besides having increased the statistical variation.

The numbers of fruit trusses per plant at flowering time are also given in Table I. In the experiments which gave large increases in fruit yield following defoliation, there were also large increases in numbers of trusses, suggesting strongly that defoliation had increased yield by causing an increase in the numbers of trusses initiated in the autumn.

In more detailed trials conducted with the varieties Talisman and Redgauntlet in 1957 and 1958, plots were defoliated on one of three dates in August, roughly corresponding to early, middle and late August. Control plots were left intact as before. Table II gives numbers of trusses and yields of sound fruit for these experiments. Defoliation in early or mid-August always increased the numbers of trusses and the subsequent crop, sometimes substantially. Defoliation in late August was usually less beneficial and in Experiment 9 the yield from Redgauntlet was depressed, but not to a level significantly below that of the controls.

Shown graphically in Fig. 1 is the relationship between number of trusses and total yield of fruit, sound and damaged, for the trials in which truss counts were made. Total yield has been used for this graph because it gives a better measure of the potential crop than does yield of sound fruit, which was strongly affected in 1958 by *Botrytis* infection. Yields of sound and of total fruit in these experiments were always directly related, so that increases in total yield within any experiment were paralleled by increases in yield of sound fruit.

The graphs suggest that yields in Redgauntlet were closely proportional to numbers of trusses, which implies that the average weight of fruit per truss remained nearly constant within each experiment. Although in Talisman there was some decline in yield per truss at the higher truss numbers, it is clear that, within the range of values recorded, truss number was the principal factor determining yield per plant in this variety as well as in Redgauntlet. The large truss numbers recorded for Talisman are related to its habit of forming many crowns.

Increases in yield following defoliation were greatest when the yields of intact plants were low. This is illustrated in Table III, where the results for all experiments with Talisman and Redgauntlet (except Experiment 3, which gave no significant differences) are listed in order of increasing yields of control plants.

Table II.

Yields of sound fruit and numbers of fruit trusses on defoliated and control plots of strawberry.

Expt. no.	Variety	Date of defoliation	Yield of sound fruit in oz. per plant				Number of trusses per plant			
			Uncut control	Defoliated	Increase over control	Least sig. increase*	Uncut control	Defoliated	Increase over control	Least sig. increase*
6	Talisman	3rd Aug. '57	7·9	13·5	5·6	2·2	14·3	27·9	13·6	3·9
		13th Aug. '57		14·3	6·4			32·9	18·6	
		23rd Aug. '57		11·3	3·4			17·9	3·6	
6a	Talisman	5th Aug. '58	18·0	25·4	7·4	3·1	—	—	—	—
		19th Aug. '58		27·3	9·3		—	—	—	—
		29th Aug. '58		27·3	9·3		—	—	—	—
7	Talisman	9th Aug. '58	31·1	34·6	3·5	1·9	36·8	44·6	7·8	4·1
		19th Aug. '58		34·2	3·1			41·9	5·1	
		29th Aug. '58		33·1	2·0			42·8	6·0	
8	Redgauntlet	3rd Aug. '57	13·5	25·9	12·4	3·7	7·8	21·6	13·8	3·3
		13th Aug. '57		23·5	10·0			18·0	10·2	
		23rd Aug. '57		17·1	3·6			15·1	7·3	
8a	Redgauntlet	5th Aug. '58	18·8	22·2	3·4	3·1	—	—	—	—
		19th Aug. '58		23·3	4·5		—	—	—	—
		29th Aug. '58		21·3	2·5		—	—	—	—
9	Redgauntlet	8th Aug. '58	23·9	31·0	7·1	3·5	14·8	17·7	2·9	2·0
		18th Aug. '58		27·4	3·5			15·0	0·2	
		28th Aug. '58		22·6	−1·3			14·0	−0·8	

* 2 × standard error of the mean.

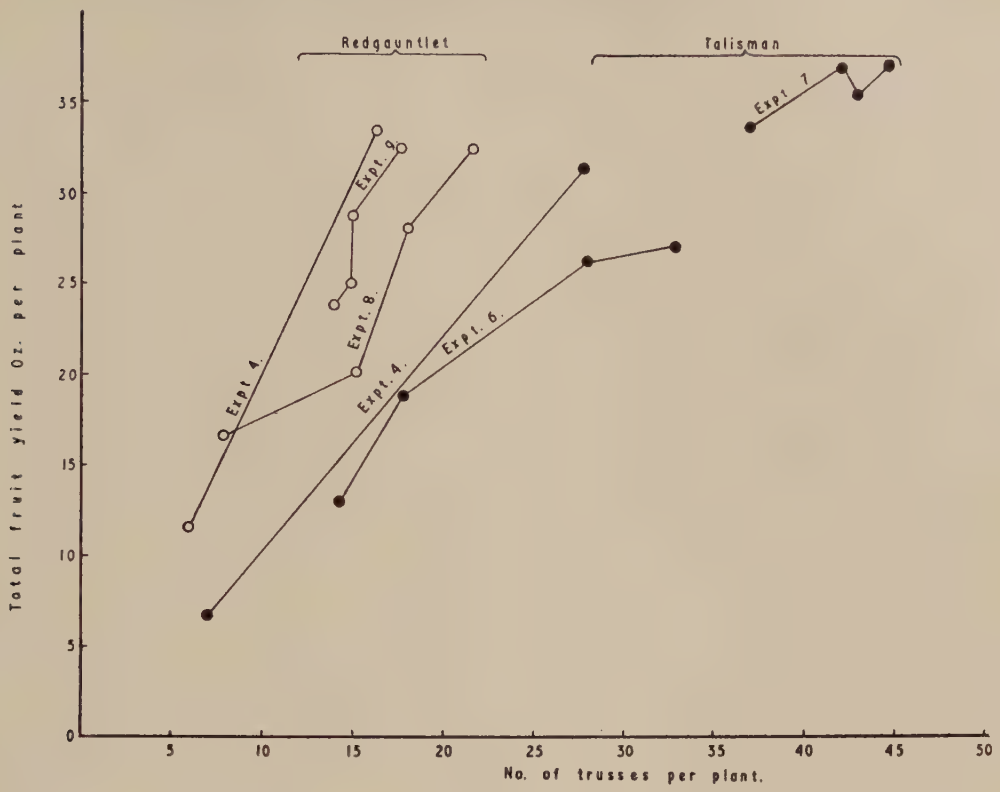

Fig. 1.
Relationship between number of trusses and fruit yield per plant.

Table III.

Total yields of fruit (sound+damaged) of intact and defoliated plants, and increments following defoliation.

Expt. no.	Variety	Yields (sound+damaged) in oz./plant		
		Control	Defoliated	Increase over control
4	Talisman	6·7	31·7	25·0
4	Redgauntlet	11·5	33·7	22·2
6	Talisman	13·0	26·8*	13·8
8	Redgauntlet	16·6	30·4*	13·8
8a	Redgauntlet	20·6	25·0*	4·4
6a	Talisman	21·3	31·1*	9·8
9	Redgauntlet	25·1	30·8*	5·7
7	Talisman	33·8	37·1*	3·3

* Mean yield for early and mid-August defoliation dates.

The effect of defoliation on fruit truss induction during the autumn of 1959 was studied more directly by dissecting samples of 48 crowns of Talisman and 24 of Redgauntlet after growth had ceased in the autumn. From the positions of the trusses within the buds an idea of the date of their initiation was obtained. Thus, trusses positioned immediately above the emergent leaf (Fig. 2, E) at the time of dissection were initiated early in September and trusses in the successively higher and younger leaf positions E—1 to E—4, were initiated progressively later in the autumn. The results of these dissections are plotted cumulatively, so that the values in the E—4 position represent the final mean number of trusses per bud. These values show that defoliation finally increased initiation by about 70% in Talisman and 50% in Redgauntlet, irrespective of the date at which the operation was carried out. As it was unusual to find more than one truss in a bud these increases were due almost entirely to the formation of trusses in a larger proportion of the crowns.

The increased production of trusses clearly occurred mainly in the E—3 position, that is, several weeks after defoliation, probably early in October. An earlier response, which doubled the number of trusses formed at the E—1 position, occurred in Talisman plants defoliated on 25th August, but not in those defoliated on 5th or

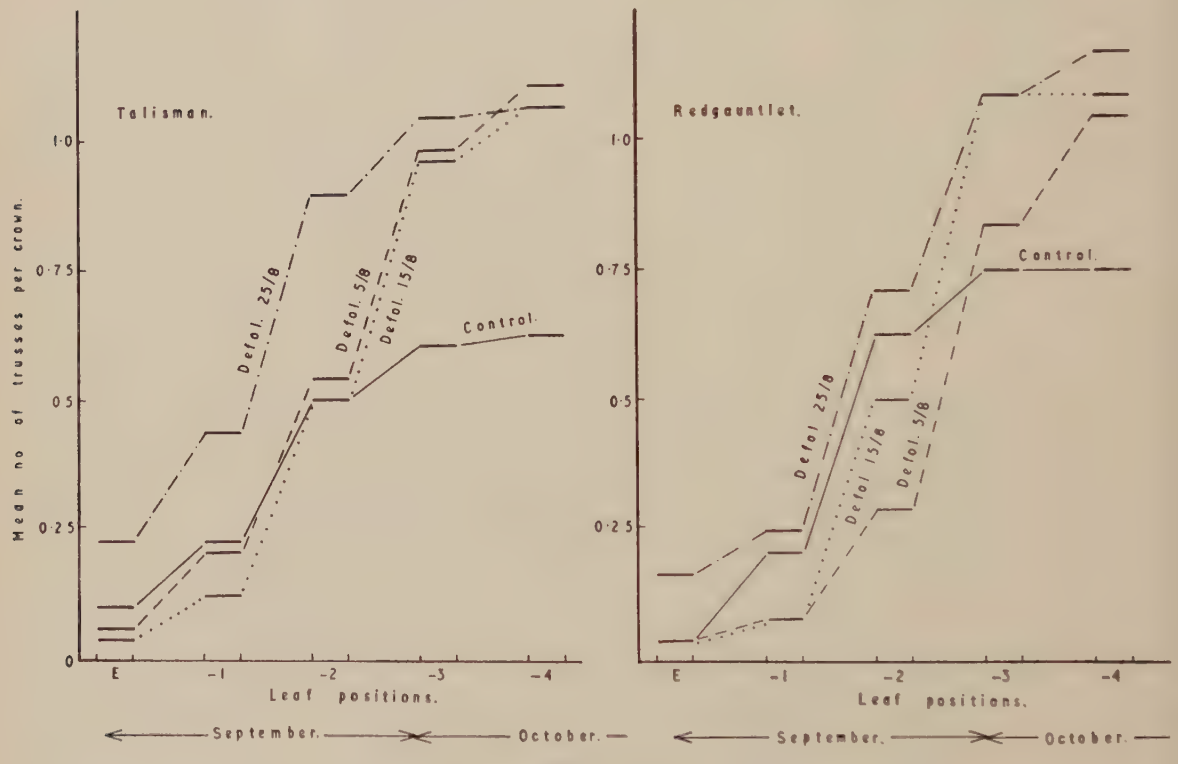

Fig. 2.

Number and distribution of fruit trusses in crowns of defoliated and intact plants of Talisman and Redgauntlet in late autumn 1959. E, last emerged leaf at time of dissection; —1, leaf in the bud immediately above the preceding, and so on. A scale of the estimated times of initiation of trusses in the different leaf positions is shown along each abscissa.

15th August. In Redgauntlet there was less evidence of this early stimulation, and indeed defoliation on the 5th or 15th August appears to have depressed the number of early-formed trusses.

DISCUSSION.

These results show that post-harvest defoliation can bring about increases in the numbers of fruit trusses formed per plant and that valuable increases of crop can then be obtained in the following year. In years when undefoliated plants were seriously deficient in trusses and had many barren crowns, the increases in yield induced by defoliation were really substantial. While it is possible that increased crown formation could result in small increases in truss numbers, this could not account for the many-fold increases reported here in large and well established plants, which had already borne at least one, and sometimes more than one, crop. Defoliation in these cases must therefore have increased the proportion of crowns which formed trusses, and this was confirmed by the bud dissections in 1959.

Yields of fruit were strongly dependent on the numbers of trusses formed, and in Redgauntlet there was little evidence that the size or yield of individual trusses declined as their numbers rose. In any plantations where truss production is the principal factor limiting fruit yields, as in the present experiments, defoliation offers a simple, relatively cheap and apparently harmless corrective. At Mylnefield this situation seems to have arisen in most years in Redgauntlet and Talisman (and formerly in Climax) and it might well be worth while to practise defoliation annually on any strongly growing, mature plantations of these varieties in Scotland. It would be rash to recommend defoliation of plantations lacking in vigour, where truss numbers in any case are not likely to be deficient. Defoliation of young plantations in the year of planting is not recommended.

Wilson and Rogers (1954) at East Malling obtained increases in yield of about 20-25% following post-harvest defoliation of the variety Huxley by mowing on 10th or 12th July. A slightly greater increase resulted from burning-off unless there was actual scorch damage. The fact that useful increments of yield were obtained with a different variety, growing in a climate which differs in some important respects from that at Mylnefield, suggests that defoliation might be usefully employed throughout the country, although the best time to defoliate may well differ between widely separated areas.

The present results support others obtained at Mylnefield under controlled environments in growth cabinets, in which fruit truss initiation was promoted by leaf removal (Thompson and Guttridge, 1960). These experiments and others (Guttridge, 1959a, b) have given evidence that day-length controls flowering by regulating the production in the leaves of a vegetative-growth-promoting hormone which is also an inhibitor of flower formation. It is suggested that fruit truss induction is inhibited in long day-lengths by a high level of the hormone, but that it occurs in short day-lengths in the absence of an inhibitory concentration of it. Foliage removal in the field in August should, on this basis, promote truss formation by removing the source of flower inhibitor. In the field, however, defoliation is followed rapidly by the emergence and unfolding of new leaves, which in a relatively long day-length may produce sufficient inhibitor to check the fall in concentration at the growing point before a level is reached at which flower induction can occur.

This may explain why defoliation is not always followed immediately by flower initiation. From the dissection results (Fig. 2) it is clear that defoliation can also induce a delayed response several weeks after cutting, by which time the plants have developed a new canopy of leaves. This can be explained if, as demonstrated by Thompson and Guttridge (1960), old mature leaves are more inhibitory than young leaves. The absence of old foliage on defoliated plants throughout the autumn should give them a prolonged advantage over intact plants in favour of flower induction, even though the inhibitor level in all plants is falling seasonally with decreasing day-length.

From the practical, commercial point of view the best time to defoliate plantations of Talisman and Redgauntlet in Scotland seems to be from early to mid-August. The timing can be expected to vary for different varieties, and further trials have been planned.

SUMMARY.

1. The fruit yields of the strawberry varieties Talisman and Redgauntlet, growing at Invergowrie, Scotland, were increased, sometimes substantially, by cutting and removing the foliage in August, soon after completion of the previous harvest. Increases of yield were inversely related to the yields of untreated control plants, and varied from fourfold when the yield of control plants was low to 10% when the controls yielded nearly 2 lb. of fruit per plant.

2. The increased yields resulted from the formation of more fruit trusses per plant, and dissections in one year (1959) showed that this was mainly due to the formation of trusses in a larger proportion of the crowns.

3. The additional fruit trusses were initiated either soon after defoliation, or several weeks later when a new leaf canopy had formed.

4. Defoliation is thought to increase truss induction by removing the source of a vegetative-growth-promoting, flower-inhibiting hormone.

5. Wherever truss formation is deficient and thereby limiting the fruit yield of unmown plants, as in these experiments, post-harvest defoliation is recommended as a corrective.

ACKNOWLEDGMENTS.

The authors wish to acknowledge the help received from Mr. R. D. Reid, the raiser of the strawberry material used, in many useful discussions on various aspects of this work ; also from Dr. D. T. Mason in the dissections and from Mrs. Margaret Robertson in the recording of the experiments in 1953 and 1954.

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OBSERVATIONS ON FLOWERING IN GLASSHOUSE TOMATO PLANTS CONSIDERED IN RELATION TO LIGHT DURATION AND PLANT AGE

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In a previous paper (Cooper, 1961) full details are given of the method of growing the plants used in making the observations now discussed. Nine sowings of the Potentate variety of tomato were made on the following dates: 27th October, 6th December 1957 ; 15th January, 24th February, 5th April, 15th May, 24th June, 3rd August and 12th September 1958. Within a few days of germination five seedlings of identical height and cotyledon length were selected and planted 6 ft. apart, in rows 6 ft. apart running east-west across a vinery-type glasshouse. Weekly observations on inflorescence development were made.

EXPERIMENTAL RESULTS.

Appearance of first flower buds.

The date of flower bud appearance was taken as that on which it was just possible, without touching the plants, to see the buds of the inflorescence among the very small leaves around the growing point.

The age, expressed as days from sowing, at which flower buds first appeared ranged from a minimum of 27 to a maximum of 47. There was a relation between this age and the mean day-length of the period from sowing to flower bud appearance, the greater the mean day-length the younger the plant at flower bud appearance. This relation is shown in Fig. 1. The data suggest that, at a mean day-length from dawn to dusk between that experienced by the January sowing (10½ hours) and the February one (12½ hours approximately), a marked change in the form of the relation occurs. A change in mean day-length below a critical value that appears to lie between 10½ and 12½ hours produces a greater effect on plant age at flower bud appearance than does a similar change above this critical value, if the relation observed is causal.

In Fig. 2 the total light (dawn to dusk) in the period between sowing and the appearance of the first flower buds is shown. It can be seen that there is no direct relation between the plant age when the flower buds appear and total light, since plants at flower bud appearance were of differing ages after similar hours of light. From a comparison with Fig. 1 the data do, however, suggest that, if light is causally related to flower bud appearance, it is most efficiently utilized at the day-lengths of the January and February sowings (i.e. approximately 10½ to 12½ hours) since at these day-lengths flower bud appearance occurs after only 370 to 380 hours of light. Any increase or decrease in mean day-length is associated with decreased efficiency of utilization of the hours of light.

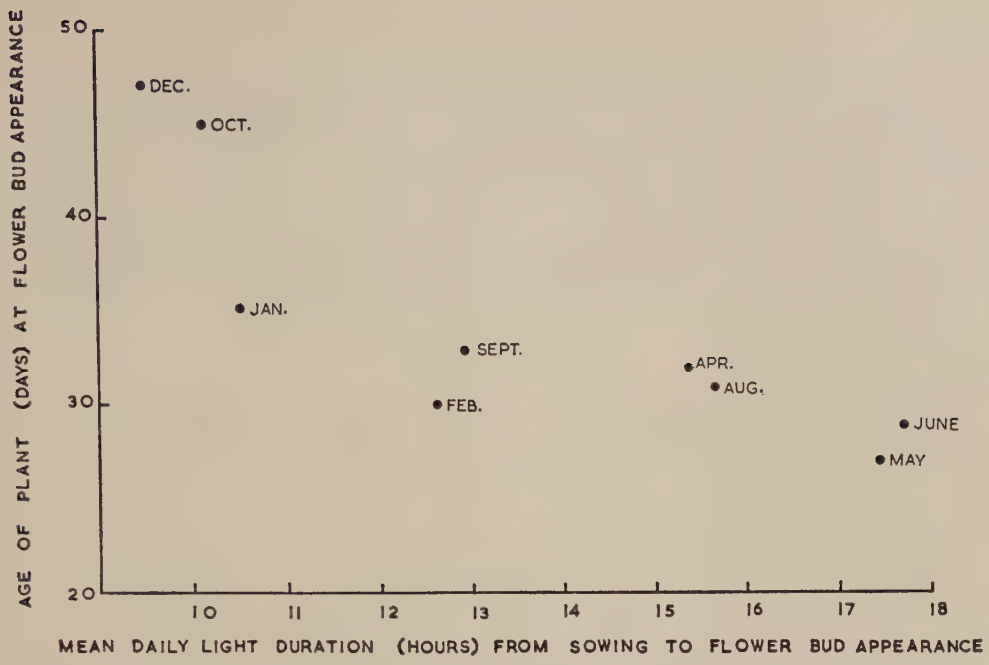

FIG. 1.

Relation between light duration and plant age at flower bud appearance, for sowings at different times of year.

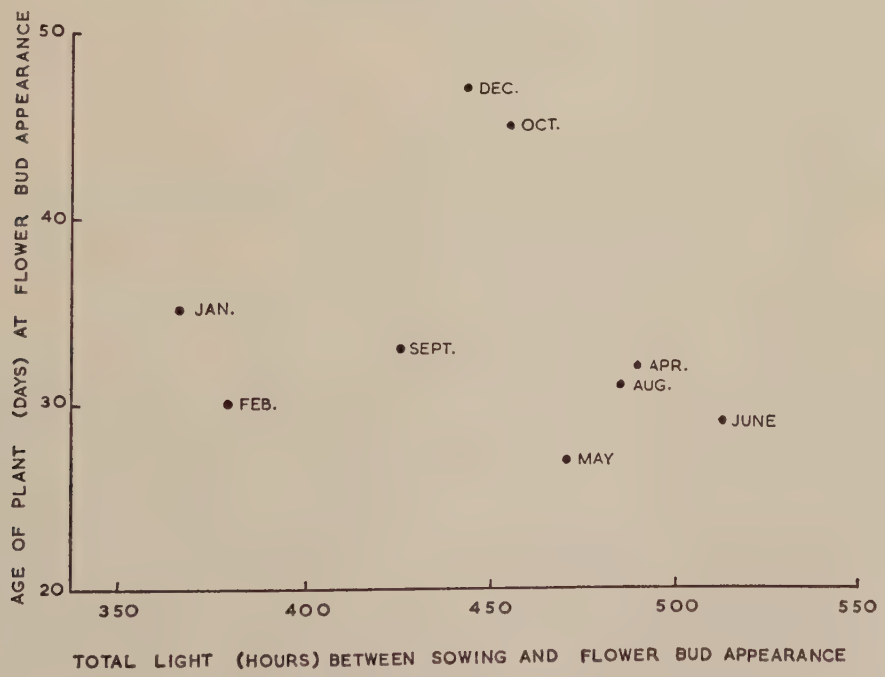

FIG. 2.

Relation between total light and plant age at flower bud appearance.

If the relations with light discussed above are causal, an associated relation with leaf area might be expected, since the light would, presumably, operate via the leaves. That there is such a relation is apparent from Fig. 3 where the total leaf length (used as an estimate of leaf area by Cooper, 1959) present at flower bud appearance is plotted against the age of the plant at flower bud appearance. The sowings fall into two distinct groups, October to February and April to September, and lines of closest fit have been fitted to the two groups. These data suggest the existence of a critical sowing date, near that of the February sowing, at which flower

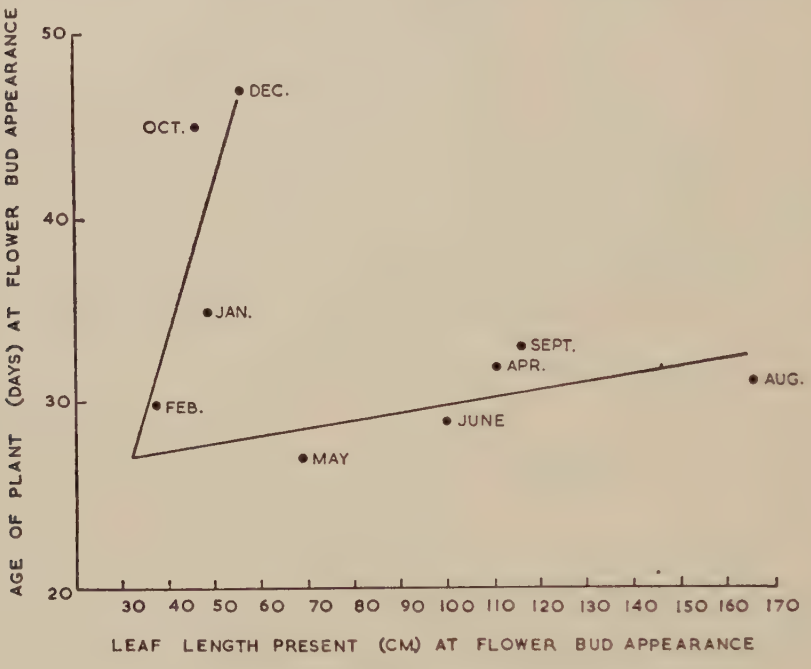

Fig. 3.
Relation between leaf area (as calculated from leaf length) and plant age at flower bud appearance.

bud appearance is attained after development of a minimal leaf area. The October to February sowings were made between the autumn and spring equinoxes when the day-length was less than 12 hours, while those from April to September were made between the spring and autumn equinoxes when the day-length was more than 12 hours. When considered in relation to the postulated critical day-length of $10\frac{1}{2}$ to $12\frac{1}{2}$ hours discussed earlier, the data suggest the existence of a day-length at which flower bud appearance is attained with minimal leaf area and that this may be the condition of equal light and darkness.

When the total leaf length present at flower bud appearance is plotted against the mean day-length from sowing to flower bud appearance, as in Fig. 4, it appears that there is an inverse relation between day-length and leaf area at day-lengths less than 12 to 13 hours (as shown by the continuous line) but that at greater day-lengths (above the broken line) the relation breaks down.

It is possible to interpret the above data by assuming that two light-dependent reactions control flower bud appearance in the tomato. In both of these the reaction rate is positively correlated with the daily light duration, but in one it is also dependent on leaf area whereas in the other it is independent of leaf area, the former reaction being limiting at day-lengths of less than 12 hours, the latter at day-lengths of more than 12 hours.

For all the sowing dates the number of buds per inflorescence varied in a similar manner, the basic trend being an increase up the plant until an inflorescence with maximal bud number was produced. At subsequent nodes, inflorescences showed a

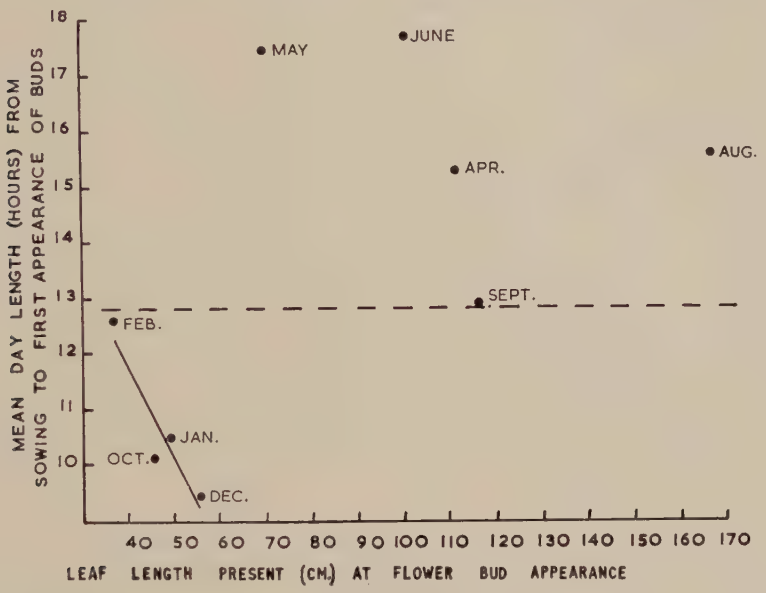

Fig. 4.

Relation between leaf area (as calculated from leaf length) at appearance of flower buds and light duration.

decline in their bud number. The position at which the largest inflorescence appeared varied with the sowing date and ranged from the fourth inflorescence to the eleventh.

There was no relation between the appearance of the largest inflorescence and the day-length at the time of appearance, the latter ranging from less than 10 to more than 17 hours.

In Fig. 5, the age of plant at which the largest inflorescence of each sowing appeared is shown plotted against the mean day-length of the period from sowing to the appearance of the largest inflorescence. As the daily light duration increased, so the age of the plant and the node at which the largest inflorescence appeared decreased, but the data suggest that, if the relation is causal, there may be a day-length above which any further increase fails to reduce the plant age at which the largest inflorescence appears. One line that could be fitted to the data has been

calculated and shown on Fig. 5. It suggests that the critical day-length may be in the region of 15 to 16 hours.

Development of first inflorescence.

It was found that, with the sowing dates used and the cultural methods practised, the development of the first inflorescence to anthesis and ovary swelling varied with the sowing date. Under favourable conditions there was a steady, relatively rapid transition from flower bud appearance through anthesis to petal fall and the swelling of the ovary. Failure to complete this process resulted from an arrest of development. When the arrest was most severe, development was checked soon after

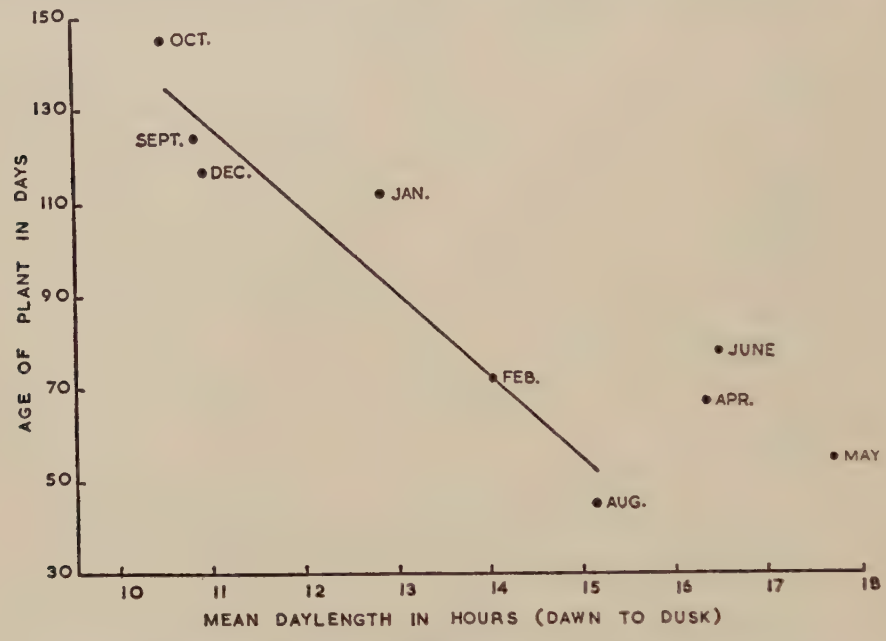

FIG. 5.

Relation between light duration and plant age at appearance of largest inflorescence.

flower bud appearance and the tiny, tightly closed buds fell off. When slightly less severe, bud development continued until the calyx tube was well formed before development was arrested. Buds of this type often remained on the plant for a long time and were capable, many months later, of experiencing slight ovary swelling, so that a very small fruit was formed without anthesis ever having occurred. A third type of arrested growth occurred when development up to petal fall was apparently normal but the ovary failed to swell. Flowers of this type also often remained on the plant for a long time and were capable, many months later, of sufficient ovary swelling to form a very small fruit. The three types of arrested development so far considered occurred mainly in the winter months on plants producing their first and second inflorescences at that time. A fourth type occurred mainly in the summer months in upper inflorescences. Development was apparently quite normal up to anthesis and then, before petal fall occurred, the flower fell off.

Table I.

Development of first two inflorescences for different dates of sowing.

Sowing	Date of appearance		%Anthesis		%Fruit set	
	1st infl.	2nd infl.	1st infl.	2nd infl.	1st infl.	2nd infl.
12th Sept.	14th Oct.	21st Oct.	50	33	0	33
27th Oct.	10th Dec.	7th Jan.	0	67	0	33
X						Y
6th Dec.	21st Jan.	18th Feb.	95	100	85	89
15th Jan.	18th Feb.	11th Mar.	100	100	100	100
24th Feb.	25th Mar.	8th Apr.	100	100	94	75
5th Apr.	6th May	13th May	100	100	81	77
15th May	10th June	17th June	100	100	100	77
24th June	22nd July	29th July	100	100	100	50
3rd Aug.	2nd Sept.	9th Sept.	100	100	80	63

The percentage of flower buds in the first and second inflorescences reaching anthesis or ovary swelling may be low or high, and depends on the date of appearance of the inflorescence, as shown in Table I. The line X-Y shows the separation of the dates of appearance into two groups. Severely arrested development occurred only when the first two inflorescences appeared during a time of the year bounded by a starting date between 2nd September and 14th October and a finishing date between 7th and 21st January, i.e. approximately at the time of the year when the combination of a day-length less than 12 hours and a progressive decrease in day-length occurred ; outside these dates the percentage anthesis and fruit set was high. The definition of the seasonal limits of occurrence of this phenomenon is of practical importance.

Plant age at the commencement of flowering.

In this paper flowering is taken to mean, not the formation of floral primordia, but the reflexing of the petals that occurs a few days before rapid swelling of the ovary normally begins.

In Fig. 6 (top left) the mean plant age at which each sowing began flowering is shown. It can be seen that the plant's age at the start of flowering decreased with the progress of the sowing date from winter to summer. The cross-hatched sections are discussed later.

In Fig. 6 (right) the mean night-length (dusk to dawn) up to the start of flowering for each sowing is shown. There is a highly significant positive correlation ($r = +0{\cdot}79$) between age at flowering and mean night-length. It is thus possible to explain, at least tentatively, the differences in plant age at flowering by postulating a causal relation between age at flowering and night-length.

A different interpretation, however, is suggested by Fig. 6 (bottom left) which shows the total amount of daylight (dawn to dusk) received up to flowering. All sowings, except that of October, began to flower when the accumulated hours of light received was approximately 700-800, irrespective of age or time of year, unless the large deviation of the October sowing is regarded as being an effect of the time of the year. That this may be so is suggested by the fact that, under the cultural conditions used (including heavy watering and unrestricted root run from germination onwards),

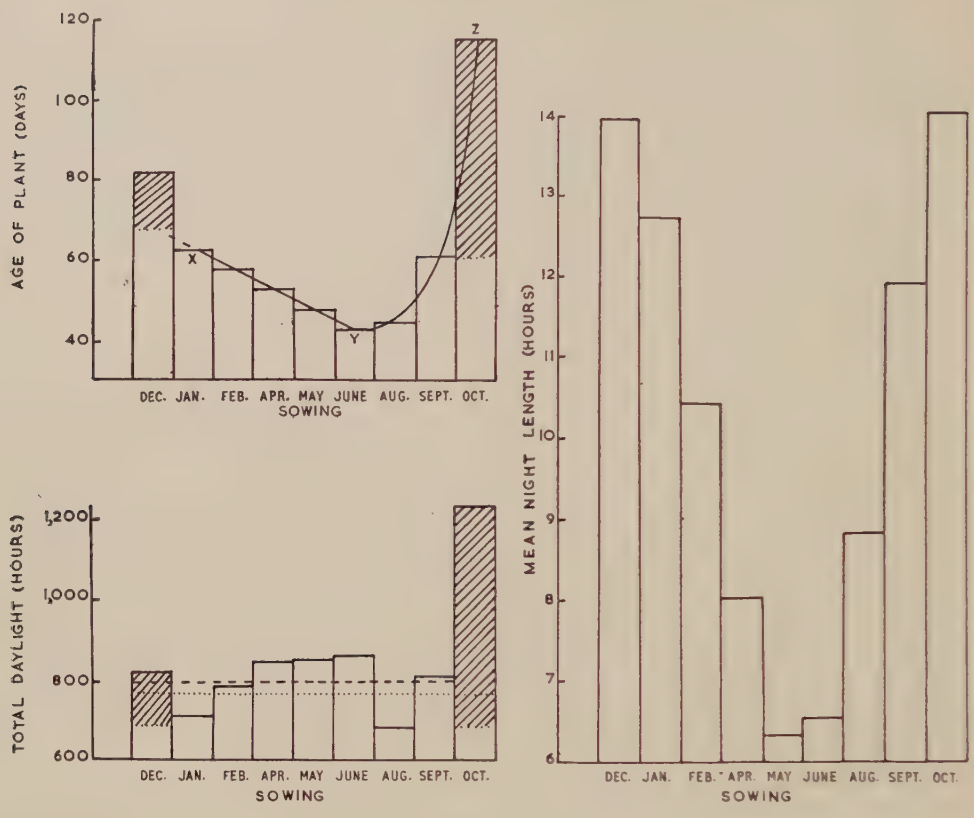

FIG. 6.

Start of flowering in relation to plant age, total light received and mean night-length.

the complete development of the first inflorescence was prevented in the October sowing, the first flowers to reflex their petals being those of the second inflorescence. This postulated basic light requirement for flowering is shown by the upper broken line, indicating the mean hours of light received by all except the October sowing.

Seasonal trends in flowering.

In Fig. 7 the weekly rate of flowers reflexing their petals is shown for the longest-lived plant of each sowing. The variability between plants was so slight that no benefit was derived from using, for a shorter period of time, the mean value derived from the five plants in each sowing. To illustrate the degree of variability the mean values for the April sowing have also been shown (as a continuous line).

The trend in flowering is similar for all sowings and consists of a rise to a maximal rate followed by a decline to a low level. This low level was in some sowings (February to August) followed by a phase of progressively increasing rate of flowering. This recovery appears to be associated with the lengthening of the days when the

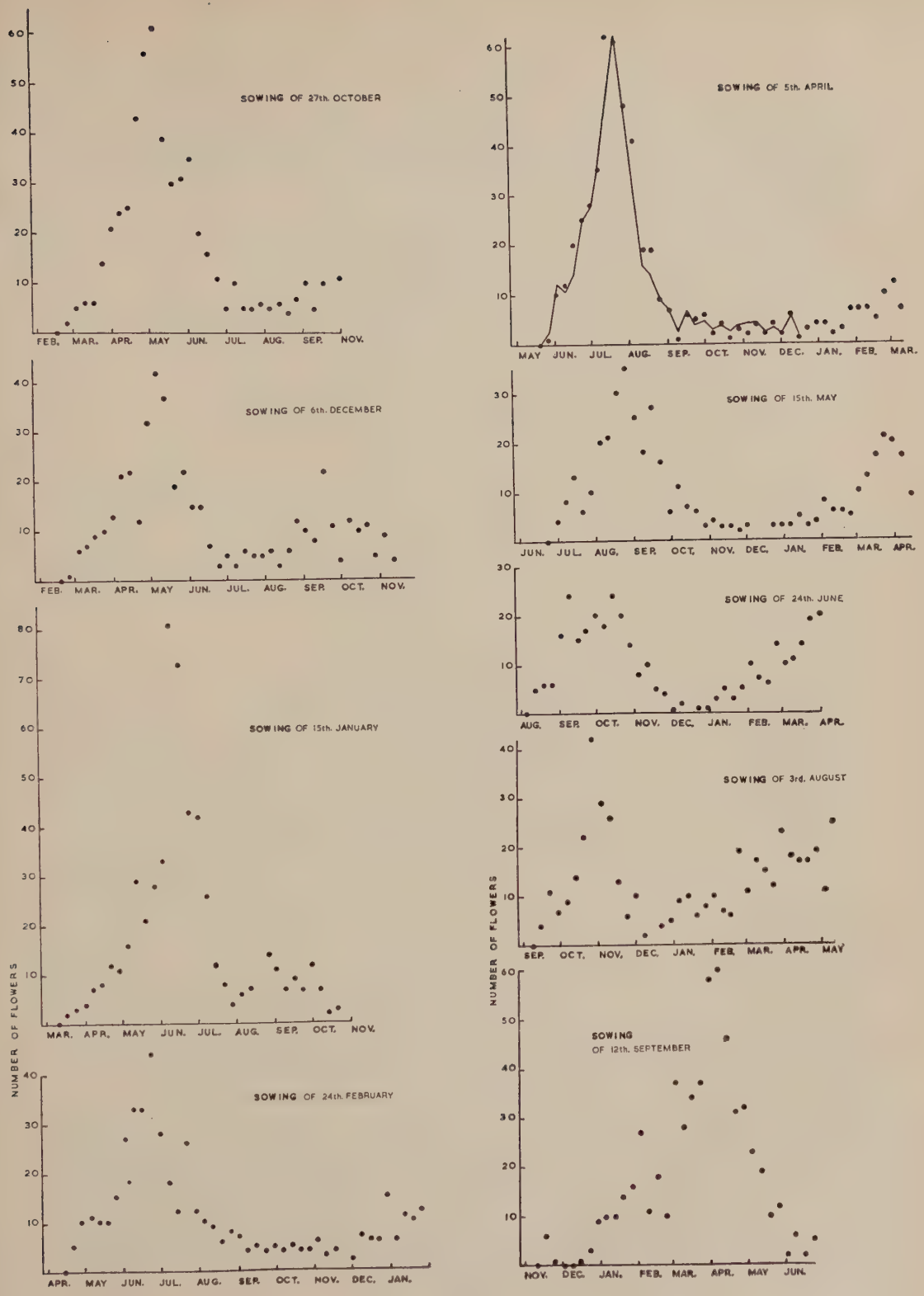
SOWING OF 27th. OCTOBER
FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. NOV.
SOWING OF 5th. APRIL
MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR.
SOWING OF 6th. DECEMBER
FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV.
SOWING OF 15th. MAY
JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR.
SOWING OF 24th. JUNE
AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR.
SOWING OF 15th. JANUARY
MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV.
SOWING OF 3rd. AUGUST
SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY
NUMBER OF FLOWERS
SOWING OF 24th. FEBRUARY
APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN.
SOWING
OF 12th. SEPTEMBER
NOV. DEC. JAN. FEB. MAR. APR. MAY JUN.

FIG. 7.

Weekly rate of flowers reflexing petals, for sowings at various dates.

shortest day is past, as can be seen from Table II. All the coefficients, except that for the February sowing, are significant at the 0·01 level of probability. The low value of the non-significant coefficient is due to the very few data that were available for its estimation.

TABLE II.

Correlation coefficients between day-length and rate of flowering during recovery phase.

Sowing				
24th Feb.	5th Apr.	15th May	24th June	3rd Aug.
+0·4	+0·8	+0·8	+0·9	+0·8

When the day-length is decreasing and the low rate of flowering has been reached, flowering remains at a low level irrespective of the length of the day. As soon as the shortest day is past and the days lengthen, the very high correlation between day-length and rate of flowering shown in Table II occurs. This suggests that there may be an interaction between light duration and the direction of the change in light duration.

In Table III the number of days from the start of flowering to the attainment of the maximal rate of flowering is shown for each sowing.

The outstanding feature is the very long time from the start of flowering of the September sowing to the attainment of its maximal rate of flowering. This was the only sowing that began flowering under the condition of very short and progressively shortening days, and during the 32 days from 18th November (when it began flowering) to the shortest day it produced the extremely small total of only 8 flowers per plant. This suggests that such a condition may have an adverse effect on flowering and raises the possibility that, if the light duration in the early stages of development had been any shorter than that experienced by the September sowing, flowering would not have begun at all. The October sowing did experience the condition of an even shorter light duration, progressively shortening, in the early stages of development and the number of days to flowering was greater than in any other sowing and flowering first began on the second inflorescence. A coincidence apparent in Table III is that the sowings of October and December behaved, with respect to flowering, as if they had been sown on the same date, both beginning to flower on 25th February (on the second and first inflorescences respectively) and attaining their maximal rates of flowering on 6th May. This suggests the possibility that, under the condition of short and progressively shortening days, and with the cultural conditions used (including unrestricted root run and heavy watering), there is no effective physiological progress towards flowering (i.e. petal reflexing, not the initiation of floral primordia) until the days begin to lengthen. The period of time that the two sowings were under this light condition is represented in Fig. 6 (top left) by cross-hatching. If the days after the shortest day are regarded as the only ones that contribute to the progress of these sowings towards flowering, it is of interest that the plant age at flowering so calculated is similar for both sowings (60 and 67 days) and the age at flowering of the December sowing then lies on the line X-Y in Fig. 6.

Table III.

Effect of sowing date on interval from start of flowering to date of maximal rate of flowering.

Date of sowing	27th Oct.	6th Dec.	15th Jan.	24th Feb.	5th Apr.	15th May	24th June	3rd Aug.	12th Sept.
Date of start of flowering (i) ..	25th Feb.	25th Feb.	18th Mar.	22nd Apr.	27th May	1st July	12th Aug.	16th Sept.	18th Nov.
Date of attainment of maximal rate (ii)	6th May	6th May	10th June	24th June	15th July	26th Aug.	9th Sept.	28th Oct.	7th Apr.
No. of days between (i) and (ii) ..	71	71	85	64	50	57	29	43	141

It is also of interest to note that, if the hours of light received by the October sowing during this period up to the shortest day (shown by cross-hatching in Fig. 6, bottom left), during which it is postulated that there was no physiological progress towards flowering, are subtracted from the total hours of light received up to flowering, then the October sowing no longer deviates markedly from the basic light requirement for flowering of 700-800 hours as postulated earlier. The same adjustment for the December sowing is also shown cross-hatched. When the mean hours of light received by all sowings prior to flowering (including the adjusted values for the October and December sowings) are then calculated, the postulated effective light requirement for flowering to begin is 768 hours. This value is shown as the lower broken line in Fig. 6 (bottom left).

Maximal rate of flowering.

In Fig. 8 is shown the age of plant for each sowing at which the maximal rate of flowering was attained. It can be seen from Fig. 7 that, in all sowings except the September one, the number of flowers appearing each week rose rapidly and fairly steadily to the maximal rate once flowering had begun. Although this sowing began flowering on 18th November it was not until the end of December that the real rise to the maximal rate began. If the postulate that short and progressively shortening days produce little or no physiological progress towards flowering is invoked, then the interpretation can be made that for the September sowing (and presumably for those of October and December) the days from sowing to the shortest day played little part in the progress of the plant towards the attainment of its maximal rate of flowering. If this number of days is deducted from these sowings the re-calculated ages of the plants on attaining their maximal rates of flowering will be as shown by the dotted lines in Fig. 8. The data from the October and December sowings suggest that this interpretation may be correct since, despite the 40 days difference in sowing date, the maximal rate of flowering was attained on the same date, viz. 6th May. The sowing of 12th September, however, attained its maximal rate of flowering 30 days earlier. This suggests that 30 of the days from 12th September to the shortest day were not ineffective in causing physiological progress towards flowering, and that the true date of the commencement of the ineffective period was 13th October, the date of the dawn to dusk equinox. If the light/dark conditions of these 30 days are considered as resulting in progress towards flowering and are consequently not deducted from the age at the attainment of the maximal rate of flowering of the September sowing, the age so calculated is as shown by the dashed line in Fig. 8. All days ineffective in causing physiological progress have thus been subtracted from the September, October and December sowings. In the January sowing the days from sowing to germination would also be ineffective (as in all sowings) as far as any light effect was concerned and, if the days of the germination period are subtracted then the age of the plants of the January sowing on attaining the maximal rate of flowering would be as shown by the dotted line in Fig. 8.

If it is true that a progressively shortening light duration (dawn to dusk) of less than twelve hours is ineffective in producing progress towards the maximal rate of flowering, then, when such days (plus the days of the germination period) are subtracted from the total time in days from sowing to maximal flowering, the re-calculated ages at maximal flowering of all sowings made between approximately

the dawn-dusk equinox and the shortest day should be the same irrespective of sowing date. It can be seen from Fig. 8 that the ages so adjusted of the plants sown in September, October, December and January are 138, 136, 136 and 139 days respectively, thus suggesting that the postulates made may be correct.

The data discussed in this paper suggest that the tomato may not be entirely day-neutral with respect to flowering, and there is some support for this hypothesis

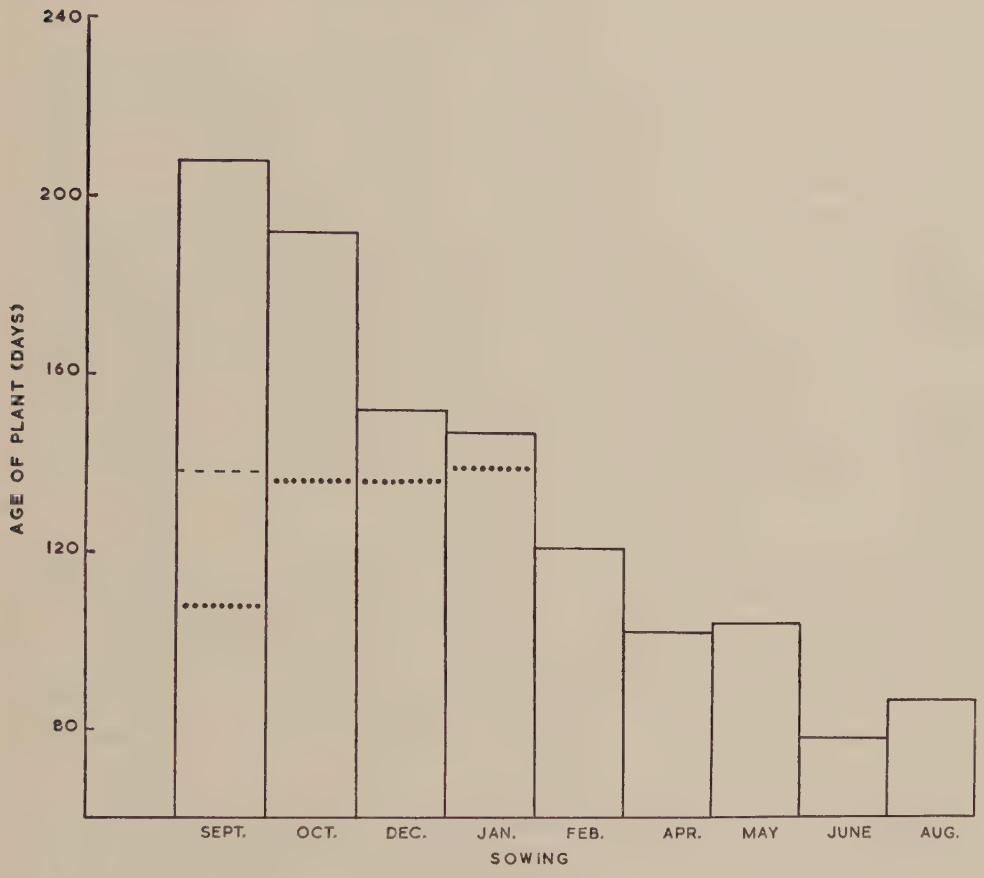

Fig. 8.
Plant age on attaining maximal rate of flowering.

in the literature. Learner and Wittwer (1953) compared tomatoes grown in a winter light duration of 9-10 hours with plants given an additional 6 hours of fluorescent light, and drew the conclusion that " the supplementary light exposure resulted in larger plants which flowered an average of 3 days earlier and with a significantly greater percentage of normal flowers in the first cluster ". Burk (1929) reported a sensitivity of pistil growth to light duration : with a light duration of 8 hours the pistils were much longer than the stamens, whereas with a light duration of 16 hours they did not extend beyond the stamens. Withrow (1945) found that by ex-

tending winter light duration of seedling tomatoes by 4 hours for 3 weeks he obtained " a definite increase in fruit production . . . on the first clusters ". Verkerk (1955) reported a similar sensitivity to day-length for dry weight in the tomato and found that the dry weight of both the root system and the stem increased as the day-length was increased up to 14 hours ; with a further increase to 16 hours the dry-weight decreased.

SUMMARY.

Seed of the Potentate variety of tomato was sown at 40-day intervals from October 1957 to September 1958 and weekly observations on inflorescence development were made over an unbroken period of 20 months covering part of 1957, the whole of 1958 and part of 1959, until each plant reached an advanced age approaching 12 months.

It was found that the age at which flower buds first appeared was correlated with day-length, the greater the day-length the younger the plant at flower bud appearance. The data suggest that the condition of equal light and dark may also be important, in that at day-lengths of less than 12 hours a greater effect is observed for a given change in light duration than at day-lengths of more than 12 hours.

There was no relation between the age of the plant at flower bud appearance and the total hours of light received. There was, however, a relation between leaf area at flower bud appearance and day-length. Flower buds appeared with minimal leaf area at a day-length approximating to 12 hours, any increase or decrease in light duration being associated with an increase in leaf area. At a day-length of approximately 12 hours the flower buds appeared after the minimal total light had been received.

An inverse relation was observed between plant age at appearance of the inflorescence with the largest bud number and the mean day-length of the growing period. This relation held up to a critical day-length, above which it did so no longer.

Failure of the lower inflorescences to complete their development coincided with the existence of a light-dark condition in which a day-length shorter than the night-length was coupled with a progressive decrease in day-length.

The age of plant at which flowering began was greater in the winter than in the summer.

When the sowing date was 27th October and there was *unrestricted root run and heavy watering*, flowering was completely arrested in the very short days of midwinter (the shortest day being approximately 9 hours from dawn to dusk).

The seasonal trends in flowering are discussed in relation to light duration, the direction of change in light duration and the condition of a daily excess of darkness over light.

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A COCOA SHADE AND MANURIAL EXPERIMENT AT THE WEST AFRICAN COCOA RESEARCH INSTITUTE, GHANA

II. SECOND AND THIRD YEARS

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In a previous paper Cunningham and Lamb (1959) pointed out that little is known of the nutrient and shade requirements of cocoa in West Africa. They described a shade and manurial experiment in which remarkable responses in yield were obtained in the first year. Two further seasons' yield data together with soil and plant analyses are presented here and from them a nutrient balance sheet has been prepared. A physiological investigation on this experiment is the subject of a subsequent paper by Hurd and Cunningham (1961).

Methods and materials.

Experimental area and design. These were fully described by Cunningham and Lamb (1959).

Fertilizer application. Table I shows the fertilizer application record to date. Initially in 1956 an arbitrary NPKMg mixture was used. The nitrogen content of this mixture was increased in 1957 and more potassium was added in 1959.

Pest and disease control. Capsid control was maintained during the last two seasons by spraying the cocoa canopy with BHC by means of a motor mist blower. Spraying against black pod was carried out each season. The method finally adopted was the application of 1% Perenox by motor blower every three weeks over the period May to July, with two more applications in September-October. The loss of pods from all pests and diseases in the two seasons reported here did not exceed 2%.

Records and harvesting. The harvest period in each season extended from 1st April to 31st March. In 1958–59 harvesting was carried out every two weeks and in the following season every week. Pod counts were made in the field and the beans from each treatment were fermented and dried separately in a central fermentary. Appropriate conversion factors (Table IV, column 8) were obtained for each individual harvest throughout the season and the yields are presented in pounds of dry cocoa per acre.

Preliminary investigations were also started to elucidate the effect of the various treatments on pod, husk and bean weights. At the peak of the minor and major harvests of each year (see Fig. 1), 50 pods were selected from each treatment. From these samples estimates were made of the average weight of a pod and its wet and dry bean and husk weights. Analyses were also carried out to determine the nitrogen, phosphorus, potassium and magnesium concentrations in samples of fermented beans and oven-dry husk from each treatment.

Soil. Since the publication of the previous paper by Cunningham and Lamb (1959), Burridge and Cunningham (1960) have demonstrated the extreme variability of the surface horizons of Ghanaian forest soils. It must therefore be concluded that the previous sampling of the soil at 20 cores per acre was inadequate. In 1959, the 0–2 in. and 2–6 in. soil horizons of each plot were sampled at 80 cores per acre. This was done at the end of the main harvest, prior to the annual leaf-fall which takes

Table I.

Scheme of fertilizer applications.

Date	Application	Fertilizers used in mixture	Rates in lb./acre*			
			N	P	K	Mg
October 1956 ..	1	Ammonium phosphate Single superphosphate Sulphate of potash Magnesium sulphate	13	40	75	27
April 1957	2	Urea Triple superphosphate	50	13	0	0
September 1957 ..	3	Urea	50	0	0	0
April 1958 ..	4	Urea Triple superphosphate Sulphate of potash Magnesium sulphate	50	44	62	30
September 1958 ..	5	Urea	50	0	0	0
April 1959 ..	6	Urea Triple superphosphate Sulphate of potash Magnesium sulphate	50	44	83	30
September 1959 ..	7	Urea	50	0	0	0

* In this paper, rates are presented on an elemental basis:
Ammonium phosphate, 11% N, 20% P
Single superphosphate, 8% P
Triple superphosphate, 20% P
Sulphate of potash, 40% K
Sulphate of magnesium, 10% Mg
Urea, 46% N

place in January–February, whereas in the first year the soil was sampled after the leaf-fall. These differences in rate and time of sampling preclude any valid comparison between the previous soil data and those presented in this paper. Organic carbon, total nitrogen and pH values were estimated by conventional methods. Available phosphorus was obtained by the method of Truog (1930) and mineralizable nitrogen determined by the simple incubation technique described by Cooke and Cunningham (1958). Exchangeable potassium and magnesium were determined from the N ammonium acetate leachate by the EEL flame photometer and the method of Cheng and co-workers (1951, 1953) respectively.

RESULTS.

Treatment effects on the yield of cocoa.

Three seasons' post-treatment yields of cocoa are presented in Table II. The percentage increases following the removal of shade and addition of fertilizer have been calculated from these data and are recorded in Table III. There is no doubt of the beneficial effects of both treatments, particularly that following the removal of shade. The data given in the Tables also reveal a definite and positive interaction of shade removal and fertilizer application.

Table II.

Three seasons' yields expressed in lb. dry cocoa per acre.

Treatment	Season		
	1957–58*	1958–59†	1959–60‡
Shade, no fertilizer	586	958	756
No shade, no fertilizer	1,100	2,348	2,187
Shade, fertilizer	849	1,211	906
No shade, fertilizer	1,602	3,091	3,088

* These are adjusted yields. Analysis of covariance gave largest standard error of difference as 86·5. See Cunningham and Lamb (1959).

† Unadjusted yields. Analysis of variance gave:
Significant difference at P=0·05, 304 lb. dry cocoa/acre
,, ,, at P=0·01, 461 ,, ,, ,, ,,
,, ,, at P=0·001, 741 ,, ,, ,, ,,

‡ Unadjusted yields. Analysis of variance gave:
Significant difference at P=0·05, 220 lb. dry cocoa/acre
,, ,, at P=0·01, 333 ,, ,, ,, ,,
,, ,, at P=0·001, 534 ,, ,, ,, ,,

Table III.

The percentage increase in yield over three seasons following removal of shade and addition of fertilizer.

		Season		
		1957–58	1958–59	1959–60
Shade removal effects	With fertilizer	89	155	241
	Without fertilizer ..	88	145	189
Fertilizer application effects	With shade	45	26	20
	Without shade	46	32	41
Combined effects of shade removal and fertilizer application		173	223	308

In the presence or absence of fertilizer, shade removal has significantly increased the crop to a greater extent each year ($P=0\cdot01$ in the first year and $P=0\cdot001$ in the second and third years). This increase in response to shade removal without fertilizer can be explained by the growth of the shade trees making shade conditions more extreme with time. The addition of fertilizer would further stimulate the growth of these shade trees and would result in an even greater contrast in the degree of shade between the treatments.

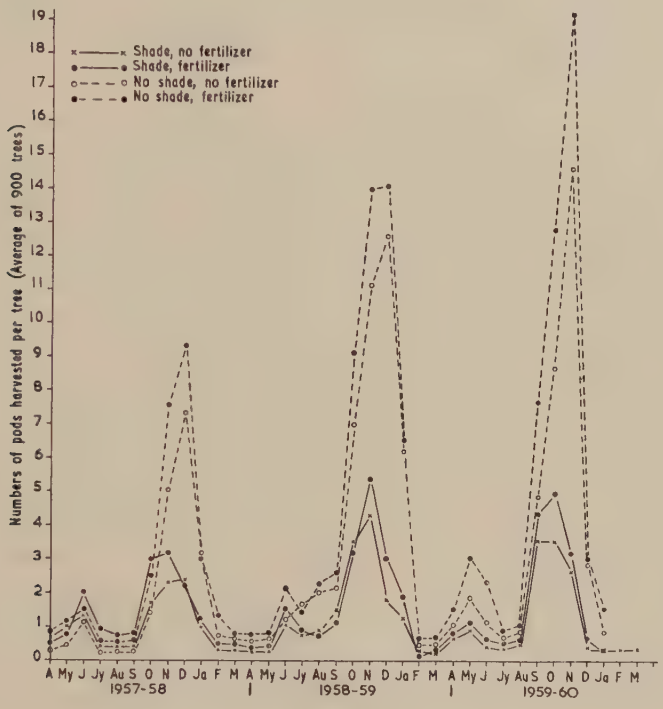

Fig. 1.
Harvest distribution.

In each season the fertilizer treatment has resulted in a significant increase in yield of about the same order in the unshaded cocoa. However, in the shaded plots, the response which was significant at $P=0\cdot05$ in the first year did not attain significance in the second and further decreased in the third year. Increased shade caused by the response of the shade trees to the fertilizer dressing offers the most likely explanation of this gradual decline.

Another interesting effect of shade removal has been the effect on the distribution of the harvest (Fig. 1). In each season the duration of the main harvest has been extended by approximately four weeks in the unshaded plots and the harvest peak has been delayed by the same period. Possible explanations of these effects are discussed by Hurd and Cunningham (1961).

Treatment effects on pods and beans.

From the preliminary data available and presented in Table IV, it appears that the treatments have not influenced the number of beans in a pod but have produced slightly smaller beans, particularly under no shade. This suggestion that smaller beans are produced by some treatments is confirmed by the more comprehensive data presented in the 8th column of the Table and it was found that, throughout the two seasons, the conversion factor was persistently best in the shaded, unfertilized plots. De-shading has increased the weight of the husk with the result that the pods are slightly larger. More detailed measurements are required in future seasons.

Chocolate has been made from the beans of all treatments and the flavour of all samples has been satisfactory.

Treatment effects on the soil, and a mineral nutrient balance sheet.

After 3 years the effect of the various treatments on the soil was as shown in Table V. Although Ghanaian forest soils are lightly buffered and five seasons' application of 4 cwt. per acre of sulphate of ammonia have been known to lower the pH by almost 1 unit, there is no indication in this experiment that urea is having such a drastic effect on the soil's pH. Exchangeable potassium levels, particularly in the 0–2 in. layer, have decreased where yields are high and have not been maintained where potassium has been applied. The levels of exchangeable magnesium have increased slightly in the fertilized plots. There has been an appreciable build-up of available phosphorus in the surface 2 inches of this undisturbed soil but no movement below that level. The available phosphorus levels are extremely low where no fertilizer has been added and there are indications, from the unpublished results of a factorial experiment at W.A.C.R.I. on the same soil, that this element produces the greatest response in yield. There are lower levels of organic carbon and total nitrogen in the top 2 inches of soil in the absence of shade and, when incubated, this soil produces less mineral nitrogen.

A nutrient balance sheet for the four treatments in this experiment is given in Table VI. A comparison with an average Ghanaian peasant cocoa farm and a modern, temperate-climate, cash-cropping system is also presented. The balance sheet has been derived from the data given in Tables I, II and IV. In preparing a nutrient balance sheet involving a perennial crop, the cycle of nutrients between plant and soil must be taken into account. The main losses from this cycle are by crop removal and leaching and the gains are by fertilizer application. In this balance sheet no allowance has been made for leaching. It should also be borne in mind that pod husks, which decompose slowly and are difficult to compost, are not returned to the soil in Ghana.

The balance sheet shows that, in the absence of shade, considerable amounts of mineral nutrients are taken off in the crop each season. On the other hand, under shade and particularly on the average Ghanaian peasant farm, yields of cocoa are so low that only small amounts of mineral nutrients are lost to the system. Although fertilizer application has substantially reduced the large deficits, it is clear from the evidence presented in Table VI that the tree's nutrient requirements differ in the two shade treatments and some improvements can be made to fertilizer proportions and rates in future seasons. Under shade, a reduction can be made in the application of nitrogen, magnesium and possibly phosphorus; in the absence of shade, the

Table IV.

Pod, bean and husk weights (gm.), mineral concentrations, etc., for 1958-59 and 1959-60.

Treatment	Pod weight	No. of beans per pod	Individual bean weight	Weight of air-dry beans per pod	Weight of oven-dry husk per pod	Ratio of oven-dry husk to air-dry bean	No. of pods per 1 lb. of air-dry cocoa	Mineral concentrations							
								Fermented bean % Air-dry basis*				Husk % Oven-dry basis			
								N	P	K	Mg	N	P	K	Mg
Shade No fertilizer	429	44	1·18	52	62	1·19	11·3	2·17	0·40	1·2	0·19	0·93	0·09	5·4	0·19
No shade No fertilizer	437	43	1·12	48	66	1·37	12·1	2·22	0·44	1·2	0·19	0·82	0·09	4·3	0·21
Shade Fertilizer	391	43	1·14	49	56	1·14	12·0	2·08	0·40	1·2	0·20	0·95	0·10	4·3	0·19
No shade Fertilizer	449	43	1·12	48	67	1·39	11·7	2·24	0·39	1·2	0·20	0·97	0·11	5·0	0·20

* These beans were not oven-dried because of their high oil and fat content (55–60%). Average water content of air-dry beans was 4–5%.

TABLE V.

Soil analyses at end of 1959-60 season; each value is the mean of 3 plots.

Treatment	Horizon	pH	% C	% N	C/N	Available P in p.p.m.	Exchangeable bases m.e./100 gm.		Mineralization of nitrogen in p.p.m.		
							K	Mg	Change in NH_4—N	Change in NO_3—N	Change in total mineral N
Shade	0–2 in.	6·7	3·12	0·297	10·5	7	0·44	4·00	−18	+106	+88
No fertilizer	2–6 in.	6·6	1·01	0·118	8·6	2	0·26	1·92	+11	+33	+44
No shade	0–2 in.	6·7	2·58	0·231	11·2	5	0·33	3·92	−16	+88	+72
No fertilizer	2–6 in.	6·4	0·78	0·089	8·8	1	0·15	1·25	+10	+24	+34
Shade	0–2 in.	6·5	3·13	0·291	10·8	33	0·46	4·10	−20	+109	+89
Fertilizer	2–6 in.	6·4	0·97	0·111	8·7	3	0·28	2·58	+5	+32	+37
No shade	0–2 in.	6·4	2·70	0·248	10·9	35	0·32	4·25	−20	+97	+77
Fertilizer	2–6 in.	6·3	0·90	0·106	8·5	2	0·18	2·00	+11	+28	+39

Table VI.

Mineral nutrient annual balance sheet.

Crop and location	Treatment	Yield in lb. dry cocoa/acre	Nutrients removed annually in beans in lb./acre				Nutrients removed annually in husk in lb./acre				Total nutrients removed annually in lb./acre				Nutrients applied annually in lb./acre*				Surplus or deficit in lb./acre			
			N	P	K	Mg	N	P	K	Mg	N	P	K	Mg	N	P	K	Mg	N	P	K	Mg
W.A.C.R.I. cocoa shade and manurial experiment†	Shade No fertilizer	857	19	3	10	2	9	1	55	2	28	4	65	4	0	0	0	0	−28	−4	−65	−4
,,	No shade No fertilizer	2,268	50	10	27	4	25	3	132	6	75	13	159	10	0	0	0	0	−75	−13	−159	−10
,,	Shade Fertilizer	1,059	22	4	13	2	11	1	52	2	33	5	65	4	100	44	83	30	+67	+39	+18	+26
,,	No shade Fertilizer	3,090	68	12	37	6	41	5	214	8	109	17	251	14	100	44	83	30	−9	+27	−168	+16
Average Ghana peasant cocoa	Shade No fertilizer	200	4	1	2	<1	2	<1	13	<1	6	1-2	15	1	0	0	0	0	−6	−1-2	−15	−1
U.K. potatoes, peas, barley, wheat‡	4 years modern cash cropping rotation	—	—	—	—	—	—	—	—	—	100	14	90	—	100	25	110	—	0	+11	+20	—

* Season 1959-60, see Table I.
† Mean of the yields for seasons 1958-59 and 1959-60.
‡ Data are approximate and have been calculated from Tables III, V and VI of Fertilizers, Crop Production and Soil Fertility by G. W. Cooke—Journal of the Farmers' Club, Part 5, 1959.

potassium application must be appreciably increased and the magnesium dressing reduced to at least half its present amount.

Dry season effect on cocoa.

Unshaded cocoa at Tafo appears to be unaffected by a mild dry season. However, in January-February 1959, there were only 2·5 inches of rain and frequent dry winds. During this period, defoliation and terminal branch die-back took place, mainly at the edges of the plots where there was no side protection. At the height of the drought there were no significant differences between soil moistures in the shaded and unshaded cocoa. These observations suggest that, when soil moistures are low and the transpiration rate is increased, severe defoliation followed by die-back takes place. It would seem therefore that, during the dry season, side protection is desirable for cocoa growing without overhead shade.

DISCUSSION.

The most spectacular result of this experiment to date has been the very large, highly significant (P = ·001) response to the removal of shade both with and without added nutrients (Table II). These responses have been maintained over three seasons and have demonstrated quite conclusively that, provided pests, diseases and weeds are controlled and soil conditions are favourable, cocoa yields will be highest in full daylight. It would appear, therefore, that in the past the role which shade plays in the culture of cocoa has been misinterpreted. Some of its main functions probably have been the suppression of weeds, the reduction of insect damage and the limiting of dry air movement rather than the provision of low light intensity.

Although the effects of fertilizer application are not as remarkable as those of shade removal, they are of considerable economic importance, especially in unshaded cocoa where there is a positive interaction between shade removal and fertilizer application. It would seem that, with shade, significant fertilizer responses can only be obtained under medium to light shade since the shade trees, if allowed to grow unchecked, will tend to offset any beneficial effects produced on the cocoa by the fertilizer. This means that under shade the application of fertilizer each season must be accompanied by the progressive thinning of shade trees.

A combination of shade removal and fertilizer application has produced in two seasons yields of just over 3,000 lb. of dry cocoa per acre. This greatly exceeds the previous best yields reported for Amelonado in West Africa and emphasizes that the potential yield of Amelonado has been considerably underrated.

The balance sheet (Table VI) reveals several interesting points. The annual nutrient removal by cocoa only approaches that of an intensive, cash-cropping system when yields are of the order of 2,000 lb. dry cocoa per acre. Normally, the Ghanaian farmer is content with what are now regarded as very low yields and has not subjected the soil to a heavy drain of nutrients. Now, however, the picture is gradually changing. Satisfactory pest and disease control, the introduction of more vigorous varieties and the reduction of shade will all contribute to a steady increase in yields which will be accompanied by a heavier drain on the soil's nutrient reserves. In these circumstances, the cocoa grower should regard the application of fertilizer not only as a means of increasing yields but also as a replacement of those nutrients which have been removed by the crop.

SUMMARY.

The yields, harvest distribution and soil data of the second and third year of a shade and manurial experiment on bearing cocoa are presented and discussed. A mineral nutrient balance sheet has been drawn up and the effect of the various treatments on pod and bean size has been given. Provided all other important growth-limiting factors are adequately controlled, cocoa yields are highest without shade. The need for fertilizer is greatest without shade, and the drain of nutrients from the soil by cocoa only becomes excessive when yields approach 2,000 lb. dry cocoa per acre.

ACKNOWLEDGMENTS.

Permission to publish this work has been given by Mr. J. Lamb, Director, W.A.C.R.I., who has been closely associated with this experiment since its beginning. His help, advice and criticism have been invaluable. The writers wish to thank Mr. T. H. R. Hall, Agronomist, W.A.C.R.I., for his supervision of the harvesting and collection of yield data during the 1959–60 season.

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A COCOA SHADE AND MANURIAL EXPERIMENT AT THE WEST AFRICAN COCOA RESEARCH INSTITUTE

III. PHYSIOLOGICAL RESULTS

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A SHADE and fertilizer experiment has been described and the effects of the treatments on yields and the soil have been discussed in two preceding papers (Cunningham and Lamb, 1959; Cunningham *et al.*, 1961). It was considered that a knowledge of the use of fertilizer application and shade removal in the culture of cocoa would be inadequate without a study of the effects of the treatment on the physiology of the cocoa tree. The results presented here are concerned with the influence of added nutrients and increased light intensity on the vegetative growth of the trees and their flowering, setting and wilting behaviour.

Pound (1936) reported on the influence of fertilizers on the physiology of cocoa and reviewed earlier work. Later, the physiological aspects of an extensive shade and fertilizer trial carried out in Trinidad (Evans and Murray, 1953) were discussed by Murray (1954). The present results to some extent collate the earlier findings and enlarge them, particularly with regard to " cherelle wilt ".

Methods.

The experimental trees were Amelonado cocoa which were 13 years old in May 1960. The layout of the experiment has been given in the first paper of this series (Cunningham and Lamb, 1959). There were four treatments, each with a total of 900 trees; they comprised shade with and without fertilizer, and no shade with and without fertilizer. Shade was completely removed by poisoning in April 1957 and an NPKMg mixture was added at intervals since October 1956. Details of these fertilizer applications are given by Cunningham *et al.* (1961). Each treatment was divided into three plots and in 1958 physiological records were made on 30 trees from one of these plots in each treatment. In 1959 this was increased to 90 trees by recording 30 trees from all three plots of a treatment.

The total number of open flowers on all the trees was recorded on one day each week. The flowers stay open for approximately two days ; accordingly a rough correction factor of 3·5 has been used in the table to convert from the weekly record to the total number of flowers produced by the trees.

The number of flowers which set was calculated weekly from the increase in the number of pods on the trees, after correction for wilted and harvested pods. All young fruits (termed cherelles) exceeding 1 cm. in length were included for this purpose. Since cherelles which have wilted do not fall off, they were counted weekly and then removed. The wilting referred to here is of physiological origin and is similar to June drop of apples.

Cocoa grows intermittently in " flushes ". Estimates of flushing were made weekly using the scoring system of Greenwood and Posnette (1950). The scores for all the trees were added together ; this arbitrary figure gives a good indication of the flushing behaviour of the trees although there is appreciable variation between individuals. With this system flushes are not recorded until about two weeks after bud-bursting.

Pods were harvested fortnightly in both years. Stem diameters and canopy measurements were made on all the trees in the experiment. Only 12 trees from each treatment were used for the leaf counts because of the difficulties in measurement.

RESULTS.

Since the results for the two years showed a similar pattern, only those for 1958 will usually be described.

Flowering.

In the absence of shade, flowering was considerably stimulated and was enhanced by the presence of fertilizer (Table I). Under shade, fertilizer had a smaller stimulating effect.

Table I.

Estimated flowering per tree; total of weekly flower counts × 3·5.

Year	Shade		No shade	
	No fertilizer	Fertilizer	No fertilizer	Fertilizer
1958	973	1,170	2,649	3,331
1959	490	820	1,171	2,385

Four main peaks of flowering occurred in both years at fairly regular intervals between February and July, while over the rest of the year very little flowering took place (Fig. 1). Although the treatments stimulated flowering they did not affect either the timing or the duration of these peaks ; only the intensity of flowering at these times was enhanced. It was noticeable that in the unshaded treatments the fourth flowering peak in June-July was very prominent, whereas it was only just discernible in the shaded treatments.

Flower setting.

Flower setting under shade was distributed over six months with a low peak in June in the middle of this period (Fig. 2). In the unshaded treatments, in response to the increased flowering, the amount of setting was correspondingly higher (Table II). Partly as a result of the greatly increased fourth flowering peak the main peak of setting came later, occurring in August.

Despite the considerable differences in the number of flowers produced in the

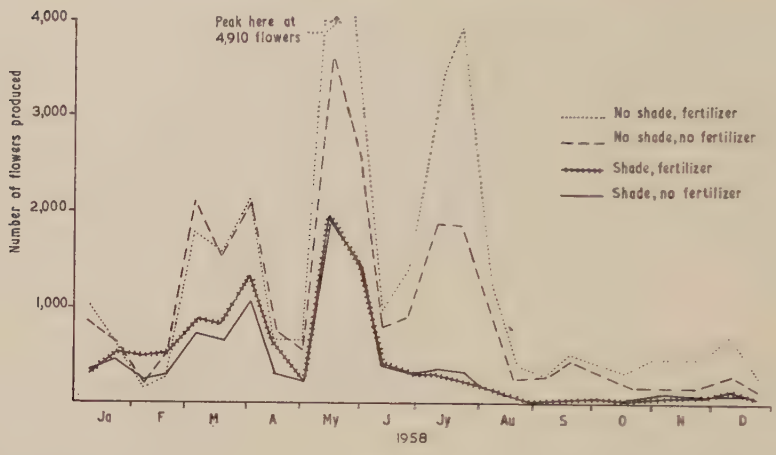

FIG. 1.

Total number of flowers produced per treatment (30 trees) every two weeks in 1958.

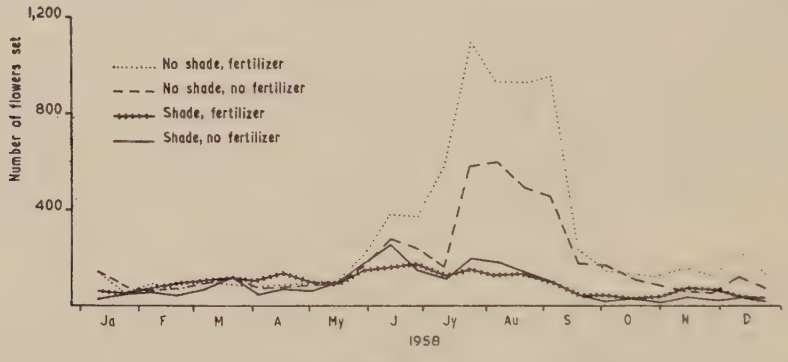

FIG. 2.

Total number of flowers set per treatment (30 trees) every two weeks in 1958.

TABLE II.

Setting and percentage setting per tree.

	Year	Shade		No shade	
		No fertilizer	Fertilizer	No fertilizer	Fertilizer
Number of flowers set	1958	67·5	72·1	159·5	232·0
	1959	39·3	60·5	143·1	223·1
Percentage setting	1958	6·9	6·2	6·0	7·0
	1959	8·0	7·4	6·0	9·4

four treatments, there was a noticeable constancy in the percentage which set (Table II). It was also observed that the percentage setting increased over the course of the year. Since the percentage setting remained roughly the same for all treatments, it was inevitable that fertilizer application influenced the number of flowers setting in exactly the same way as it influenced flower production.

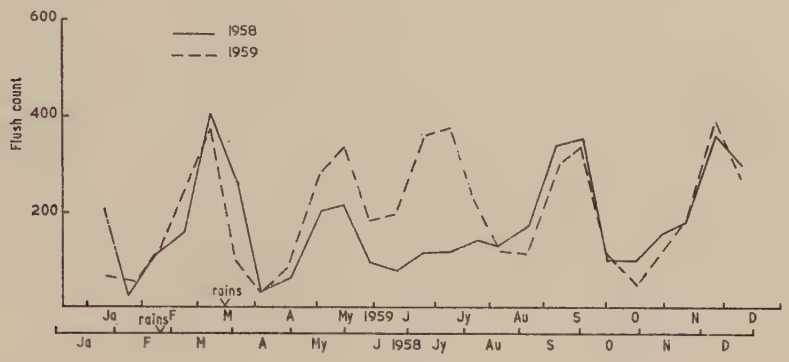

Fig. 3.

Comparison of flushing in 1958 and 1959 (only shaded, fertilized treatment shown for clarity). Each plot is the total of two weekly flush counts for the 90 trees in the treatment in 1959 and the 30 trees $\times 3$ in 1958.

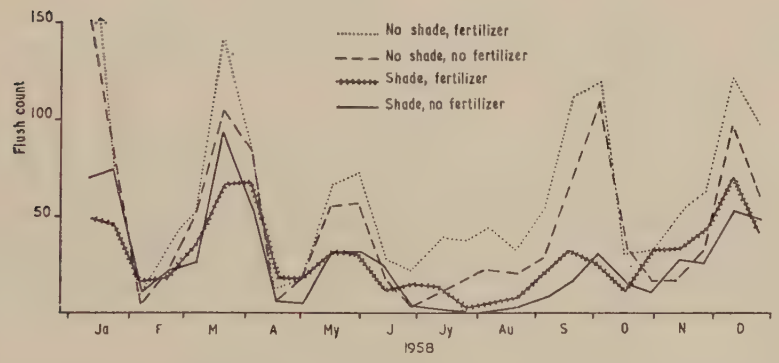

Fig. 4.

Comparison of flushing in all four treatments in 1958. Each plot is the total of two weekly flush counts for the 30 trees of each treatment.

Flushing.

There were several peaks of flushing in 1958 and 1959, occurring at identical intervals in both years but not on the same dates (Fig. 3). The trees in all the treatments flushed with the same periodicity but the unshaded trees flushed much more vigorously than the shaded trees (Fig. 4). There was a slight stimulation of flushing in 1958 by the fertilizer applications but there was none in 1959 (Table III).

TABLE III.

Amount of flushing per tree.

Year	Shade		No shade	
	No fertilizer	Fertilizer	No fertilizer	Fertilizer
1958	23·7	25·6	40·3	55·7
1959	26·5	26·0	50·5	51·9

TABLE IV.

Relation between the main flushing peak of the year and the onset of the main rains; records on 96 clonal cocoa trees (selection ACU85) planted at Tafo in 1947.

Year	Main rains	Peak of main flush	Interval
1955	15th Feb.	16th March	29 days
1956	7th March	30th March	23 days
1957	10th April	2nd May	22 days
1958	25th Feb.	25th March	28 days
1959	15th March	2nd April	18 days

The largest flush is normally associated with the onset of the main rains in February–April, as is seen from the records (Table IV) taken on clonal cocoa over the past five years. In 1958 in the present experiment a similar connection was obtained although in 1959 the relationship was unexpectedly poor (Fig. 3). In fact, in the unshaded trees this flush is by no means outstanding, unlike that found in shaded cocoa. The peaks of flowering were usually associated with peaks of flushing (compare Figs. 1 and 4), as has normally been found in other experiments at W.A.C.R.I.

An interesting difference between the two years has been the continuous cycle of flushing at regular 6–8 week intervals throughout 1959 (Fig. 3). This is unusual for cocoa at W.A.C.R.I. ; there is normally a period over June–September when no flushing takes place, as occurred in 1958 (Fig. 3). In that year there was a flush in May, followed 18 weeks later by another in September. To explain this gap normally found in the flushing cycle it has been suggested that, when the mean weekly maximum temperature in the canopy drops below 83° F. (28° C.), no flushing takes place (Humphries, 1944; Greenwood and Posnette, 1950). As noted above there is approximately a two-week interval between the time of bud-bursting and its recognition as a new flush. This makes the critical time in 1958 over the period 26th June to 27th July, and in 1959 from 6th June to 4th July. Over these periods

the mean weekly maximum temperatures were 80·5°, 82·0°, 82·5°, 82·5° F. in 1958, and 86·5°, 84·5°, 85·5°, 83·0° F. in 1959. This clearly fits in with the hypothesis and explains the additional flush obtained in 1959. Other differences in the climatic conditions, including weekly minimum temperatures, rainfall, relative humidity and sunshine hours, cannot be fitted into an explanation of this difference between the two years.

Wilting.

The main peak of wilting was associated with the high levels of setting which were obtained in the middle of the year in all treatments (Fig. 5). In the unshaded treatments this resulted in a peak of wilting in August and September in both years. In the shaded treatments, where the peak of setting came earlier, the associated peak of wilting occurred over the period from July to the beginning of September. Peaks of wilting also coincided with peaks of flushing, suggesting that there was a competition for nutrients between the vegetative and reproductive phases of growth. There was considerably more wilting in the unshaded treatments (Table V) but in spite of

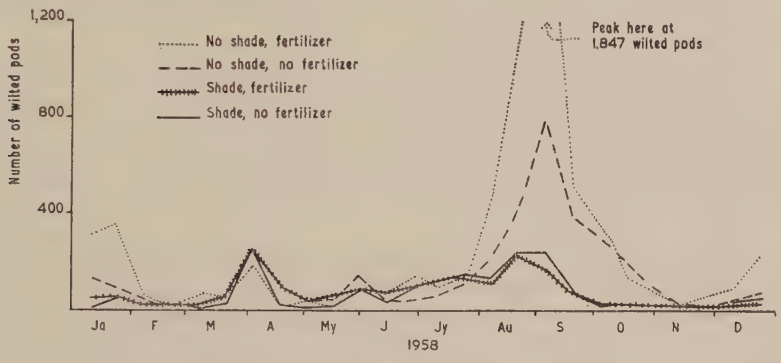

Fig. 5.

Total number of cherelles (young pods) which have wilted per treatment (30 trees) every two weeks in 1958.

this the percentage wilt over the course of the year remained approximately the same in all the treatments.

Table V.

Number of cherelles wilting per tree.

	Year	Shade		No shade	
		No fertilizer	Fertilizer	No fertilizer	Fertilizer
Number of wilted cherelles	1958	53·9	58·1	114·1	179·9
	1959	30·5	51·6	108·7	165·9
Percentage wilting	1958	79·9	80·6	71·5	77·5
	1959	77·6	85·3	76·0	74·4

Number of pods harvested.

Table VI shows the yields of pods obtained from the trees on which the other physiological records have been taken ; they agree quite closely with those given by Cunningham *et al.* (1961) for the whole area (an indication of the reliability of the other records taken).

TABLE VI.

Number of pods harvested per tree (estimated from the trees used in these records).

Year	Period of cropping*	Shade		No shade	
		No fertilizer	Fertilizer	No fertilizer	Fertilizer
1958	Mid-crop	0·8	1·9	2·1	4·9
	Main crop	11·9	12·5	37·0	43·7
	Total	12·7	14·4	39·1	48·6
1959	Mid-crop	1·2	1·5	4·4	7·1
	Main crop	8·5	10·0	31·0	42·9
	Total	9·7	11·5	35·4	50·0

* Mid-crop from 1st April to 31st July, main crop over rest of year.

The unshaded trees yielded considerably more than the shaded trees and the addition of fertilizer produced a further smaller increase.

Fig. 1 in the paper just cited shows that in each year the peak of the harvest was later in the unshaded than in the shaded treatments. It is clear that this was the result of the presence of the fourth flowering peak which was so much greater in the unshaded treatments. Because of this the bulk of the setting occurred later and this delayed the peak of the crop.

There was a considerably greater mid-crop in the unshaded treatments in 1959 than in 1958. There was also a record national mid-crop in this year.

Other effects of the treatments on the trees.

There is no doubt that of the two treatments the removal of shade had by far the more important influence on the tree. It resulted in the average light received by the leaves of the trees increasing from 15 to 57% of total daylight. This estimate was made by using a series of oxalic acid actinometers set up above and below the canopy during a week in August 1959. The actinometers were 100 ml. tightly bunged conical flasks containing 10 ml. of oxalic acid at concentrations between 0·1 N and N and 1 ml. of 0·0005 M uranium acetate solution. The amount of light quanta received is quantitatively related to the amount of oxalic acid decomposed (Leighton and Forbes, 1930). The reaction is sensitive only to the blue end of the spectrum, but this is adequate to give a fair estimate of the percentage light penetrating the canopy.

Leaf counts were made at the beginning and end of the dry season in November

1959 and March 1960 (Table VII). Removing the shade resulted in a highly significant increase in the number of leaves on the tree, there being 62% more in November and 94% more in March. This increase over the dry season is probably associated with a flush in the unshaded cocoa in January which was less marked in the shaded treatments. Fertilizers on the other hand did not increase the number of leaves significantly in any except the unshaded November treatment.

Table VII.

Number of leaves per tree as affected by shading and fertilizing treatments; mean of 12 trees in each treatment.

Treatment	Nov. 1959	March 1960	Difference
Shade, no fertilizer	731±48	689±47	−42
Shade, fertilizer	722±55	651±66	−71
No shade, no fertilizer ..	969±70	1,268±110	+299
No shade, fertilizer	1,252±63	1,330±92	+78

Table VIII gives estimates of the distance between the base of the canopy and the ground ; the distance to the top of the canopy was difficult to assess but appeared to be higher in the shaded treatments. From the Table and this observation it is clear that the unshaded cocoa had developed a lower habit of growth, there being less self-pruning of the lower branches. This was presumably because much more light was received by these branches in the unshaded treatments. This difference in growth habit is advantageous since it allows simpler methods for harvesting and other cultural operations. In approximately two years the trunk diameters of the unshaded trees increased significantly compared with those under shade. Fertilizer appears to have had no effect.

Table VIII.

Canopy base and trunk diameter per tree; mean of all the trees in the trial (900 trees per treatment). Records made in January 1959.

Parameter	Shade		No shade	
	No fertilizer	Fertilizer	No fertilizer	Fertilizer
Mean distance from canopy to ground in feet	10·24±0·61	9·21±0·66	8·64±0·31	7·46±0·32
Mean trunk diameter (cm.) at 6 in. from ground	9·14±0·12	9·04±0·12	9·97±0·10	9·90±0·11

DISCUSSION.

These results have shown the effects of fertilizer and shade removal on some aspects of the physiology of the cocoa tree. It is now possible to understand more clearly how these two treatments are operating in increasing the yield.

The unshaded trees have a considerably larger number of leaves as a result of their more vigorous flushing. A combination of the greater leaf area and the higher light intensity have no doubt considerably increased the carbohydrate production of the trees. Blackman and Wilson (1951) showed that the net assimilation rate increased with increasing light up to full daylight in a range of plants, whether they were ecologically "shade" or "sun" plants. It was also proposed by Murray (1954) that there was a relation between yield and the amount of light available in cocoa, provided that mineral nutrients were not limiting.

The basic rhythm of growth shown by cocoa has been discussed by Pyke (1933) and McKee (1944) and is clearly shown here, particularly in the unshaded treatments. Some features of this rhythm can be seen from a comparison of the different treatments. It is not influenced either by changes in factors that affect nutrition (fertilizer application and the removal of shade) or by temperature variations (there is a 2 or 3° F. temperature difference in the canopy of shaded and unshaded cocoa). Only the intensity and not the frequency of the peaks is affected. Other factors, however, may suppress the expression of either flushing or flowering. For example, when the mean maximum temperature drops below 83° F. (28° C.) flushing is restricted, and during the latter part of the year when the crop is developing there is only a limited amount of flowering.

This rhythm resembles the endogenous rhythms found in other plants (Bünning, 1956). These are initiated by some external factor, their period is relatively little influenced by changes in the external environment, and the rhythm gradually fades out with time. However, there are differences ; light or temperature changes, which are usually the initiating factor, are unlikely to operate in Ghana where the day-length is relatively constant and the mean maximum and minimum temperatures fluctuate by no more than 8 or 9° F. over the year. A change in soil moisture seems more likely from the observed relation between the rains and the main flush, but this could be an artefact accentuating a flush already decided by the rhythm. A further difference is that in the unshaded treatments there is no indication that the rhythm is fading out with time. On the other hand, it is not possible to explain this periodicity in terms of a build-up of nutrients or growth hormones to some threshold value, since this would result in the unshaded fertilized cocoa having a much more frequent cycle than the shaded unfertilized trees.

Setting and wilting are inevitably affected by this rhythm. Setting is to some extent related to the number of flowers produced and peaks of wilting occur at peaks of flushing, presumably because of competition for nutrients (Humphries, 1943).

A constant percentage (*ca.* 6) of the flowers was set in all treatments over the course of the year, despite the considerable differences in the absolute number of flowers. Pound (1933) reached a similar conclusion, having manipulated experimentally the number of flowers produced on different trees. Any explanation of this involves insect counts since self-pollination is difficult to achieve in the cocoa flower. The alternative possibility, that 6% setting represents the percentage of flowers which are fertile, is incorrect because hand pollinations result in from 30–70% success, depending on the time of the year (McKelvie, 1958). The greater concentration of flowers either allows the same number of insects to reach more flowers or alternatively it attracts a higher insect population. Perhaps both factors are operating. The percentage of flowers setting also increases over the course of the year,

suggesting a build-up of pollinating insects. No estimates of the number of pollinating insects within the different areas are available.

Several independent investigators have concluded that cherelle wilt is primarily caused by competition for nutrients (Humphries, 1943; Murray, 1953 ; Alvim, 1954). The actual mechanism of cherelle wilt may well be auxin-activated and McKelvie (1956) showed that there were peaks of wilting which could be related to auxin levels. However, he states that " . . . it is a lack of nutrients which, in the final analysis, causes a pod to wilt ". Cherelle wilt in this respect resembles " June drop " of temperate fruit trees, and differs from " pre-harvest wilt " which is directly caused by an inadequate auxin supply (van Overbeek, 1952). It follows that one should be able to reduce cherelle wilt simply by improving the nutrient regime, provided that other factors remain unchanged. Pound (1933) found that a nitrogenous fertilizer application did reduce the number of cherelles wilting, and Naundorf (1954) noted a similar response to urea sprays. These observations were made over a limited time interval, only a month in the case of Pound's experiment. As demonstrated in the present experiment, over a longer time interval these other factors do not in fact remain constant. Cherelle production has also increased following an improvement in the nutrient regime ; more cherelles have wilted, and so the percentage wilting has remained roughly constant. Pound (1936) and Murray (1954) also found this to be true in their fertilizer experiments with cocoa. It follows from this constancy of percentage setting and wilting that within a year the ratio of the number of flowers produced per pod harvested will be the same in all treatments. In support of this there is a correlation coefficient of 89% (significant at the 1% level) between figures for flowering and pods harvested in Tables I and VII. However, this ratio varies from year to year and cannot be used to forecast the crop. This is presumably because of small variations in climate between years. For example, in a good year conditions may be optimal for the assimilation of nutrients while the crop is developing and the percentage wilt will drop below average, whereas in a bad year the reverse will be true.

The question arises as to the best time to apply the fertilizers. It would seem that an application immediately after setting, in time to affect the peak of wilting a few weeks later, would be appropriate, but the timing is too critical to be of practical value. It is also desirable to apply the fertilizer in order to affect the tree as a whole. With these two ideas in mind it is suggested that an application made at the beginning of the main rains would be most suitable. The fertilizer would then be effective in time to influence the earliest stages in the development of the crop, and also the vegetative growth of the trees, which in shaded cocoa at least is most active at this season. Hurd (1959) has shown that phosphate is most readily accumulated by cocoa over the period of the main rains and this probably applies to the other mineral nutrients as well. A second fertilizer application directed mainly towards influencing the developing crop could be given later, since there is a fairly constant four-to-five-month interval between the beginning of the rains and the critical cherelle wilting period (Hurd, 1959). Foliar sprays would probably be best for this application because they are effective almost immediately, so that the application could be delayed until visual observations confirmed the theoretical time interval.

One of the other observations which was of interest was the very large mid-crop which occurred in 1959. One important difference between the two years was that there was no flush in the dry season in January 1959, whereas there was a considerable

one in 1958 (Fig. 3), associated with a high percentage wilt. As a result, far more pods survived the dry season in 1959 and were eventually harvested as the mid-crop. It is found that normally there is a flush during the dry season at a time when water and therefore available nutrients are low. This inevitably leads to the wilting of a large number of the developing pods. It was considered that irrigation over this critical period might be of value and this is being currently investigated. One-third of all the treatments have been irrigated from January 1960 so that the available soil moisture is being maintained at a reasonable level. Already irrigation has significantly increased the number of leaves retained by the shaded trees over the dry season.

SUMMARY.

Investigations have been made of the flowering and fruiting behaviour of cocoa trees after shade removal and fertilizer application. The considerably greater yields obtained were associated with increases in vegetative growth, in amount of flowering, and in setting and wilting of the young pods.

The treatments have increased the intensity, but have not affected the periodicity, of the rhythm of flushing and flowering observed in cocoa. This is in keeping with current ideas on endogenous rhythms in plants.

The percentage of the cherelles wilting remained unchanged in all the treatments despite the considerable differences in the absolute numbers present. An explanation of this is presented.

It is recommended that fertilizers are applied at the beginning of the main rains, with possibly a later foliar application to influence the developing crop.

ACKNOWLEDGMENT.

This work is published with the permission of Mr. J. Lamb, Director of W.A.C.R.I., whose continued interest is acknowledged.

Since this paper went to press, McKelvie (J. exp. Bot., 1960, **11**, 413-24) has published some earlier work on cherelle wilt performed at W.A.C.R.I. His results and conclusions concerning the role of cherelle wilt in cocoa are entirely in accord with those presented here.

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A NOTE ON VESSEL STRUCTURE IN THE XYLEM OF ROOTS OF M.XVI APPLE ROOTSTOCK

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An anatomical feature that may be of diagnostic value in the identification of the rootstock has been observed in the xylem of M.XVI apple roots. In sections of roots, sporadic transverse reticulate to scalariform perforation plates (Fig. 1) were found in 2% of vessels. This represents a high proportion of the vessels that could have been cut exactly across the end. Further investigation revealed that most M.XVI vessels, even in small roots, possessed perforation plates of this type but, owing to the flimsy structure of the plates, they were easily damaged and lost during the preparation of the material. Thick sections were necessary since the delicate membranes fell out of thin sections, particularly when the perforation plates were obliquely placed. Intense staining with aniline blue was required to render the structure of the plates clearly visible.

Reticulate to scalariform perforation plates were not found in the vessels of any other apple rootstock selection that has so far been studied. Similar plates have been observed in other members of the Pomoideae, e.g. *Pyrus aucuparia* (Chalk, 1933), in certain *Prunus* species (Bailey, 1944 ; Metcalfe and Chalk, 1950), and in the primary xylem vessels of *Cydonia vulgaris* and *C. japonica* (Bliss, 1921), but they have not previously been recorded in *Malus*.

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PLATE I.

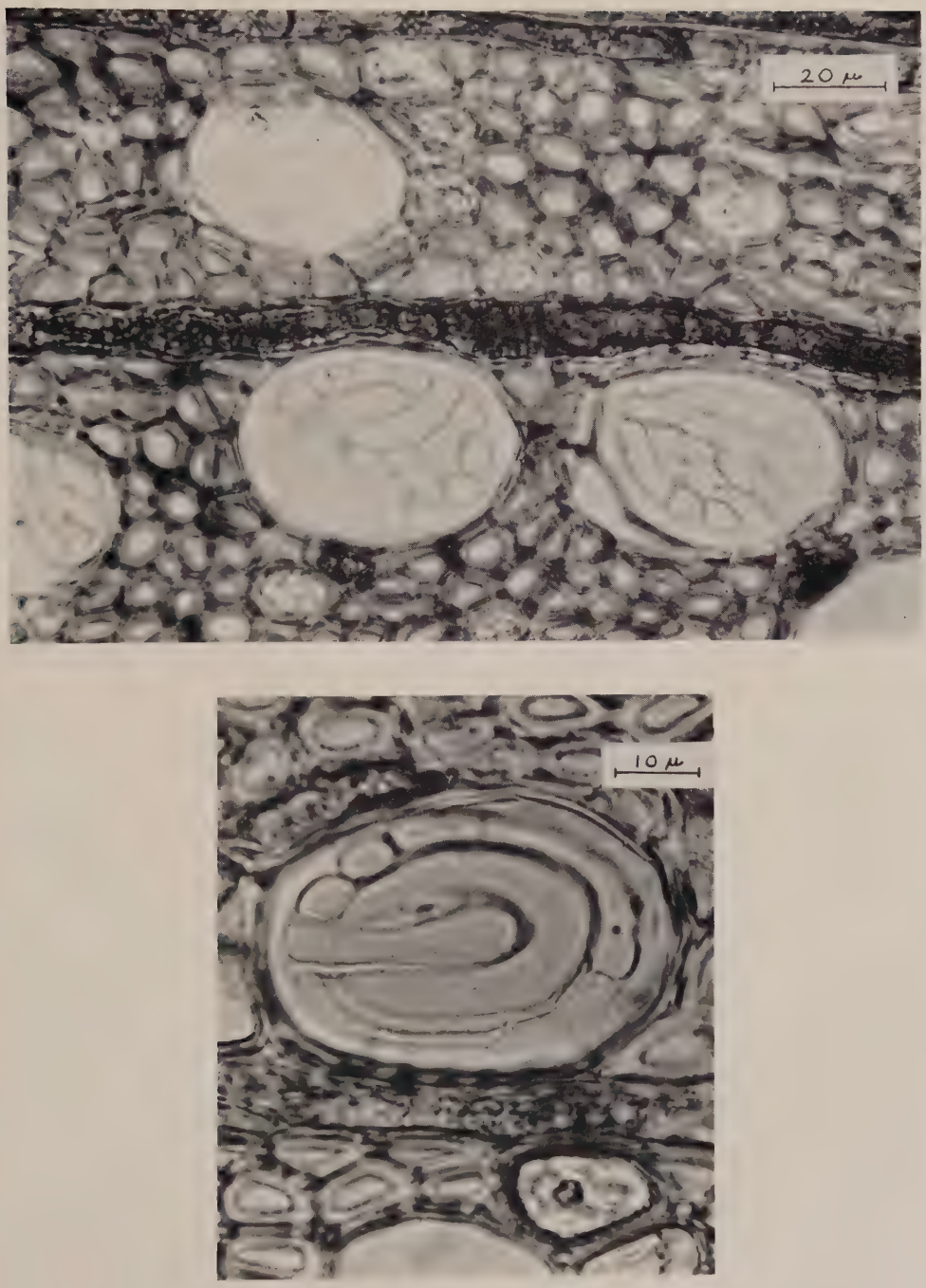

Fig. 1.

T.S. xylem from a root of M.XVI apple rootstock showing transverse reticulate to scalariform perforation plates in the vessels.

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THE NATURAL ACCUMULATION OF SOLUBLE SALTS IN THE CASING LAYER OF MUSHROOM BEDS

By P. B. FLEGG

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DURING studies on the function of the casing layer it has been found that the addition of soluble salts to it has marked effects on fruiting (Flegg, 1958 and 1959a). The characteristic response is a reduction in the number of mushrooms, but those which develop are, on average, heavier, though the total weight of the crop is usually reduced. The explanation of this phenomenon in terms of a relationship between moisture stress and fruiting has already been discussed (Flegg, 1959b). It has been observed, however, that even on untreated plots there is an accumulation of soluble salts in the casing layer during the cropping period. In view of the effect on cropping of adding soluble salts to the casing layer it is of interest and importance to discover more about this natural accumulation of salts, and whether it is likely to have any effect on fruiting and yield under commercial conditions.

Experimental methods.

It is practically impossible to stop the movement of soluble salts from the compost into the casing layer under normal cropping conditions ; therefore, the problem of assessing their effect has been approached by observing the response of the crop to small regular applications of salts supplementary to the natural accumulation.

Previous work (Flegg, 1958 and 1959a) has shown that, provided there are no nutritional or specifically toxic effects, it is immaterial which salt is used, the effect on cropping being related to the electrical conductivity of the casing layer resulting from the addition of the salt. Calcium chloride, which had previously been found to be satisfactory, was used in these experiments. Two experiments were carried out : in the first (T1) calcium chloride was added at rates of 0, 0·5, 1·0 and 2·0 gm. per sq. ft. per week, and in the second (T2) at lower levels 0, 0·2, 0·4 and 0·6 gm. per sq. ft. per week. The weekly additions of salt were applied in solution as evenly as possible over the plot surface. The first application was immediately after casing the beds and additions were continued for ten weeks. A mixture of sphagnum peat and lump chalk was used to case the beds and, apart from the addition of salt to the casing layer, the crops were grown as far as possible according to normal practice.

The experiments were carried out in trays, each of 6 sq. ft. In Experiment T1 there were four treatments laid out in three 4×4 Latin squares, and in Experiment T2 the four treatments were arranged in six randomized blocks. Throughout the experiments no extra casing material was added to the beds, and samples of the casing layer were taken at fortnightly intervals for analysis.

Determinations of the soluble salt content of the casing materials were carried

out according to a procedure previously described (Flegg, 1958). For the measurement of electrical conductivity of soil samples from a preliminary experiment, the usual water : solid ratio of 2·5 : 1 was used. With the peat and chalk samples a higher ratio was required to give a satisfactory reading. This was because of the high water-holding capacity of the peat, and a water : solid ratio of 5 : 1 was finally adopted for these samples.

RESULTS.

It was of importance to discover whether the accumulation of soluble salts in the casing layer was in any way related to the activity of the mushroom mycelium. This was investigated by observing the accumulation of soluble salts in casing soil above spawned and unspawned compost. From Table I it is evident that the movement of soluble salts into the casing layer does not depend on the presence of mushroom mycelium.

Table I.

Soluble salt content and electrical conductivity of casing soil taken from above spawned and unspawned compost; means of 5 plots.

	Soluble salts %	Electrical conductivity in millimhos
Soil at casing	0·07	0·29
Soil from spawned plots after 15 weeks	0·30	0·94
Soil from unspawned plots after 15 weeks ..	0·49	1·64

The cropping data from Experiment T1 are shown in Table II, and significant differences from the untreated plots at the 5% and 1% levels are indicated by one and two asterisks respectively. Although only the final yields after 10 weeks cropping are given, the trends shown in Table II were evident throughout the cropping period.

Table II.

Effect on cropping of regular additions of calcium chloride to the casing layer; Experiment T1.

	Weekly addition of salt (gm. per sq. ft.)				S. e. of means
	0	0·5	1·0	2·0	
Days, casing to first pinheads ..	16·6	16·5	15·9	16·8	±0·22
Weight, lb. per sq. ft., at 10 weeks ..	1·57	1·38*	1·40*	1·19**	±0·05
Numbers per sq. ft. at 10 weeks ..	61·8	52·9*	52·1*	38·6**	±2·46
Average weight (oz.) per mushroom at 10 weeks	0·41	0·42	0·43	0·49	

* Significant at P=0·05; ** Significant at P=0·01.

Thus, supplementing the natural rate of accumulation markedly affected cropping, and the response of the mushroom followed the trends already established (Flegg, 1958 and 1959a) ; numbers and yields were reduced, but the average weight per mushroom tended to increase. In Experiment T2 the weekly rates of addition of salt were less than in Experiment T1 and from Table III it is seen that there were no

Table III.

Effect on cropping of regular additions of calcium chloride to the casing layer; Experiment T2.

	Weekly addition of salt (gm. per sq. ft.)				S. e. of means
	0	0·2	0·4	0·6	
Days, casing to first pinheads ..	22·0	22·3	22·0	22·0	±0·5
Weight, lb. per sq. ft., at 8 weeks ..	1·81	1·77	1·80	1·83	±0·12
Numbers per sq. ft. at 8 weeks ..	73·6	65·2	71·5	61·6	±4·53
Average weight (oz.) per mushroom at 8 weeks	0·39	0·43	0·41	0·47	

significant effects on cropping, although at the highest level of addition, viz. 0·6 gm. per sq. ft. per week, there was a tendency for fewer but heavier mushrooms to be produced. Fig. 1 shows the change in electrical conductivity of the casing layer in all treatments of both experiments throughout the cropping period, and Table IV shows the changes in soluble salt content of the casing layer during the cropping period for all treatments of Experiment T1.

Table IV.

Changes in salinity of the casing layer during cropping; Experiment T1.

Weekly rate of adding salt	Soluble salt content of the casing layer %		
	At date of casing	After 2 weeks	After 15 weeks
0 gm. per sq. ft.	0·14	0·24	0·26
0·5 ,, ,, ,, ,,		0·30	0·57
1·0 ,, ,, ,, ,,		0·27	0·93
2·0 ,, ,, ,, ,,		0·42	1·56

DISCUSSION.

Table I shows that the movement of soluble salts from the compost into the casing layer is independent of the presence of mushroom mycelium and is, therefore, the result of physical processes. The continuous evaporation of water from the

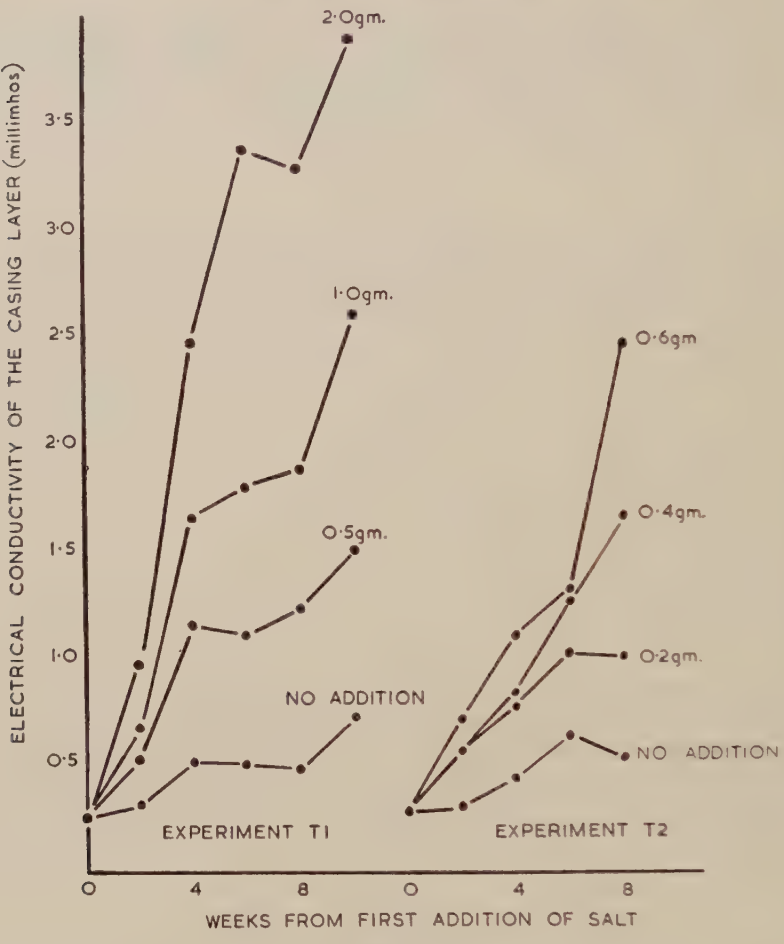

FIG. 1.

Experiments T1 and T2.

The increase in salinity of the casing layer during cropping; numbers of gm. shown are per sq. ft. per week.

surface of the casing layer will undoubtedly give rise to an upward movement of dissolved substances, and it is also to be expected that soluble salts will diffuse from the compost, which contains relatively large quantities of soluble salts, into the casing layer, which normally has a much lower salt content (Flegg, 1959a). Evidence of the latter process has been obtained from experiments in which the normal salinity of the compost was supplemented by adding soluble salts ; the amount of salt moving into the casing layer was found to be greater where the compost salinity had been artificially increased (Flegg, 1958). Thus the main factors influencing the accumulation of soluble salts in the casing layer are probably the rate of evaporation of water from the bed surface and the difference in salt concentration between compost and casing layer. This does not, of course, exclude the possibility that some of

the soluble material normally found in the casing layer may be the result of the activity of the mushroom mycelium.

Measuring the electrical conductivity of the casing material was chosen as a means of assessing the rate of accumulation of salts because, compared with the determination of the amount of soluble salt, it is quicker, more convenient and a smaller sample is required. However, the soluble salt content was determined on samples from two plots of each treatment in Experiment T1, taken at the time of casing and 2 and 15 weeks after casing. Despite an anomalous value from the samples taken two weeks after casing from the plots receiving 1 gm. of salt per sq. ft., the results shown in Table IV confirm the general trends of the electrical conductivity data.

Considering the results of both experiments together, it appears that neither the yield nor the numbers of mushrooms were markedly affected by supplementary rates of accumulation of less than 0·5 gm. of calcium chloride per sq. ft. per week. In Experiment T1, 0·5 gm. per sq. ft. per week resulted in a reduction of 12% in yield and 14·5% in numbers, whereas in Experiment T2 0·6 gm. per sq. ft. per week had no effect on yield but gave about a 16% reduction in numbers. It is clear from Fig. 1 that even a weekly addition of 0·2 gm. per sq. ft. represents a considerable supplement to the natural rate of increase in salinity. The natural increase in salinity of the casing layer found in Experiments T1 and T2 is similar to that found in several other experiments not described in this paper. It is therefore reasonable to conclude that, unless the rate of accumulation of soluble salts in the casing layer were to reach levels far in excess of those in these two experiments, there can be little danger in commercial practice of the natural accumulation of salts having any appreciable effect on yield, numbers, or average weight per mushroom. The highest concentrations of soluble salt are reached towards the end of the cropping period, and by this time most of the crop will have been picked.

The conclusion that the natural accumulation of soluble salts, under normal circumstances, has no effect on cropping behaviour is supported by data obtained from a uniformity trial not described here. The yields and the electrical conductivity of the casing layer at the end of cropping were compared and, although the electrical conductivity of the samples of casing material varied from 0·39 to 0·93 millimhos, no significant correlation with yield could be shown.

SUMMARY.

Accumulation of soluble salts in the casing layer of mushroom beds has been found to take place in the absence of mushroom mycelium, and there is evidence to show that it occurs primarily as a result of physical processes. The main factors likely to influence the accumulation of soluble salts are the rate of evaporation of water from the bed surface and the salinity of the underlying compost.

Under normal growing conditions the natural accumulation of soluble salts in the casing is unlikely to affect fruiting, yield, or average weight per mushroom.

ACKNOWLEDGMENT.

The author expresses his thanks to Miss I. Warman for her help with the experiments and subsequent analytical work.

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THE EFFECTS OF ADDING SOLUBLE SALTS TO THE CASING LAYER ON THE YIELD AND SIZE OF CULTIVATED MUSHROOMS

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For many years it has been claimed by growers that adding common salt (sodium chloride) to the casing layer during the cropping period confers some freedom from pests and diseases and increases the size of the mushrooms. Evidence in support of the former claim has already been given by Flegg and Wyatt (1959), and an increase in average weight per mushroom has been found by Flegg (1958). An increase in the average weight per mushroom had previously been shown to be associated with increased size, as measured by cap diameter and height (Flegg and Gandy, 1956). Hence the claim of larger mushrooms after such treatment also has experimental support.

Although a number of growers regularly add salt to the casing layer to prevent pests and diseases and to improve size, the practice has never been carefully studied. The recent experimental evidence (Flegg, 1958 ; Flegg and Wyatt, 1959) supporting the claims made for adding common salt to the casing layer has revived interest in its use within the industry, and it is therefore important to examine the practice and to assess its value.

From time to time growers obtain crops consisting of large numbers of small mushrooms. This entails much extra labour in picking and packing, and in addition the small mushrooms, especially in the mature " flat " stage, are easily damaged during handling. Under these conditions an improvement of average size and weight of the mushrooms would be of considerable value. There is, however, little to be gained from increasing the average weight too much, for mushrooms which are too large usually have a lower market value, but it would be an advantage to be able to exert even limited control over the size and weight of the mushrooms produced, especially if the demand for large or small mushrooms should vary.

Experimental data.

Although a number of experiments have been made to examine specifically the possibility of increasing the average size of mushrooms by adding soluble salts to the casing layer under commercial conditions, it has been found that the problem can be better assessed by including the data from other experiments, some of which have already been described and discussed from other points of view (Flegg, 1958, 1959 and 1961). Data from two recent experiments by Reeve *et al.* (1959), and two unpublished experiments sponsored by the author at the Stockbridge House Experimental Horticulture Station, Cawood, Yorkshire, are also used. These are designated here as R1 and R2, and as C1 and C2, respectively. All other experiments will be referred to by the original designation under which they have already been described (Flegg, 1958, 1959 and 1961). In all, the data from eleven experiments were available for this study, and include five in which 8-in. plant pots were used as

plots, referred to as the P series, and six in which trays of 6 sq. ft. (T1 and T2) and beds of 16 (C1 and C2) and 43 sq. ft. (R1 and R2) were used.

The soluble salts used in these experiments included sodium, potassium and ammonium sulphates, sodium, potassium, magnesium and calcium chlorides, calcium nitrate and disodium hydrogen phosphate. No specific salt or ion effects have been observed, the response of the mushroom being related to the electrical conductivity of the treated casing layer. Usually the salts were applied in solution to the casing layer soon after casing, but in two experiments, described as T1 and T2 (Flegg, 1961), small additions were made weekly over a period of 10 weeks. Apart from treating the casing layer with one of the salts, the crops were grown according to normal practice. The length of the cropping period varied from 4–6 weeks when pots were used, to 8–12 weeks in the tray and bed experiments.

RESULTS.

The detailed cropping data of each experiment are not presented as many have been published already (Flegg, 1958, 1959 and 1961, and Reeve *et al.*, 1959). In all experiments, except T2, there was a marked reduction in numbers of mushrooms and yield, together with an increase in the average weight per mushroom, in response to increasing additions of soluble salt to the casing layer. Experiment T2 does not conform to this pattern solely because the quantities of salt added were insufficient for any significant effect on cropping.

The correlation between yield and average weight per mushroom produced has been calculated for each experiment separately, and the correlation coefficients are shown in Table I. In ten of the experiments a significant negative correlation has been obtained, from which it is concluded that, when sufficient soluble salt to affect cropping behaviour is added to the casing layer, the resulting increase in average weight per mushroom is accompanied by a corresponding reduction in the total weight of the crop.

In order to examine further the relation between increase in average weight per

TABLE I.

Yield (lb. per sq. ft.) and average weight (gm.) per mushroom; correlation coefficients and regression equations for experiments on the addition of soluble salts to the casing layer.

Experiment	Correlation coefficient	Regression	Standard error of slope
P1	$-0{\cdot}38\pm0{\cdot}17$*	$y\dagger=-0{\cdot}011x+0{\cdot}91$	$\pm0{\cdot}003$
P2	$-0{\cdot}89\pm0{\cdot}10$**	$y=-0{\cdot}085x+1{\cdot}55$	$\pm0{\cdot}031$
P7	$-0{\cdot}98\pm0{\cdot}17$**	$y=-0{\cdot}053x+1{\cdot}12$	$\pm0{\cdot}022$
P12	$-0{\cdot}99\pm0{\cdot}01$**	$y=-0{\cdot}076x+1{\cdot}36$	$\pm0{\cdot}002$
P13	$-0{\cdot}90\pm0{\cdot}05$**	$y=-0{\cdot}120x+2{\cdot}20$	$\pm0{\cdot}022$
T1	$-0{\cdot}91\pm0{\cdot}29$*	$y=-0{\cdot}126x+2{\cdot}91$	$\pm0{\cdot}039$
T2	$0{\cdot}31\pm0{\cdot}14$	$y=0{\cdot}023x+2{\cdot}15$	$\pm0{\cdot}048$
C1	$-0{\cdot}84\pm0{\cdot}27$*	$y=-0{\cdot}039x+1{\cdot}05$	$\pm0{\cdot}004$
C2	$-0{\cdot}77\pm0{\cdot}29$*	$y=-0{\cdot}081x+2{\cdot}56$	$\pm0{\cdot}030$
R1	$-0{\cdot}96\pm0{\cdot}17$**	$y=-0{\cdot}276x+3{\cdot}33$	$\pm0{\cdot}047$
R2	$-0{\cdot}79\pm0{\cdot}30$*	$y=-0{\cdot}330x+3{\cdot}70$	$\pm0{\cdot}111$

* Significant at the 5% level of probability.
** Significant at the 1% level of probability.
† y, yield ; x, average weight per mushroom.

mushroom and loss of total yield, the regression of average weight per mushroom (x) on yield (y) has been calculated for each experiment and the equations are also shown in Table I. The corresponding regression lines from some of the experiments are shown in Fig. 1. From this and Table I, the reduction in yield associated with an increase in average weight is clearly evident. It is also noticeable that the slope of the regression lines varies considerably over the eleven experiments under discussion. Thus, in Experiment P1, an increase in the average weight per mushroom from 10 gm. to 20 gm. was achieved with only a slight reduction in total yield from 0·8 to 0·65 lb. per sq. ft., whereas in Experiment C2 a similar increase in average weight was accompanied by a drop in total yield from 1·75 to 0·95 lb. per sq. ft. In the experiments of Reeve *et al.*, R1 and R2, a very slight increase in average weight per mushroom was associated with a drastic reduction in yield. It is thus impossible to make any prediction of general application about the loss of yield which will accompany a given change in average weight per mushroom. The reason for this extreme variability of the slope of the regression lines is not clear ; it does

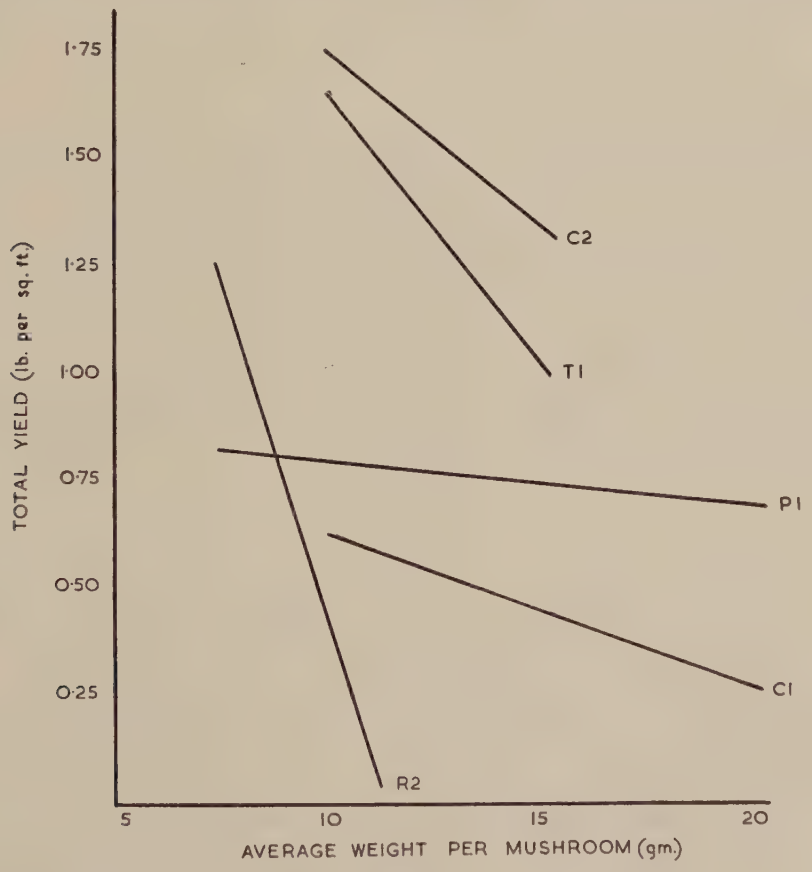

FIG. 1.

Addition of soluble salts to the casing layer; relation between total yield and average weight per mushroom. Regression lines are shown only over the range of values obtained in each experiment.

not appear to be connected with the level of productivity or with the nature of the salt used.

DISCUSSION.

In reassessing the value of the traditional practice of adding a soluble salt to the casing layer it is important to appreciate that, when sufficient salt is added to bring about an improvement in size and average weight per mushroom, then, inevitably, a reduction in the total yield will result. It is necessary, therefore, to balance the possible benefits from increased average weight per mushroom, such as reduced labour for picking and packing, and increased market value, against the probable loss of yield. Unfortunately, it is not possible to make any general statement relating crop loss and improvement of the size of the mushrooms. It is likely, however, that the greatest advantage will be gained when the crop consists of large numbers of excessively small and fragile mushrooms. In this instance the practice of adding soluble salts to the casing layer may prove extremely useful, for it appears to be the only means known as yet by which it is possible to exercise even limited control over numbers and average weight of mushrooms.

SUMMARY.

By the use of data from eleven experiments, the traditional practice of adding common salt to the casing layer of mushroom beds in order to increase the size and weight of the mushrooms produced has been examined.

It is shown that, when salt is added in sufficient quantity to increase the average weight per mushroom, a loss of yield results.

Because of the extreme variability of the relation between increased average weight per mushroom and the associated loss of yield, general recommendations are impossible.

The practice of adding salt to the casing layer is therefore not recommended as a routine measure without taking into account the possible advantages of reduced labour for picking and packing the larger mushrooms, and the disadvantage of a reduction of total yield. Where the crop consists of large quantities of small mushrooms the practice may be valuable.

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BOOK REVIEWS

FERTILIZERS AND MANURES. By Keith Paisley. (London : W. H. and L. Collingridge Ltd. 1960. Pp. 208, illus. Price 30s.)

This book, which is essentially a guide to the nutrition and manuring of horticultural crops, should prove to be of interest and value to the practising horticulturist both commercial and private, and to the elementary student. The title is rather unsuitable ; admittedly fertilizers and manures are discussed in fair detail but they are dealt with almost entirely from the horticultural standpoint, with little or no mention of their agricultural uses, and in any case fertilizers and manures form only part of the subject matter.

After preliminary sections on the basic functions and needs of plants, nutrient deficiencies and excesses, and the soil, there are chapters on green manuring, liming, inorganic and organic fertilizers, organic manures, composts, liquid feeding, etc. Inorganic and organic fertilizers and manures are dealt with thoroughly and without bias.

The last four chapters are concerned with the manuring of vegetables, fruit, garden flowers, lawns and glasshouse crops. Here the author's practical experience in market gardening and as Senior Lecturer at the Kent Horticultural Institute has stood him in good stead with those crops for which there is little or no experimental evidence on manuring. Throughout, the book is practical and positive in its approach without much attempt at critical discussion. Indeed, it would hardly be possible to deal critically with the wide range of subject matter in a book of only moderate size.

There is a useful index and an appendix giving analytical details of fertilizer materials. The type is excellent but the illustrations are of variable quality ; in particular, those of mineral deficiencies in horticultural crops are rather unsuccessful. Such subjects generally need colour rendering for satisfactory results. There are a few misprints, e.g. 3 per cent. for 0·3 per cent. on page 25 and 10 cwt. instead of 20 cwt. in the table on page 55. The amounts of lime recommended in this table are rather high by many standards.

W.D.

THE MANGO. By Lal Behari Singh. (London : Leonard Hill Books Ltd. 1960. Pp. 438, illus. Price 84s. net.)

It is good news that full and satisfactory books are now being written on the important crops of the tropics. Last year appeared *Bananas* by N. W. Simmonds in the Tropical Agriculture Series ; now is published this comprehensive work *The Mango*, the first in the World Crops Books series of which the General Editor is N. Polunin.

Simmonds in his book comparing annual world production thinks it is possible that the most abundantly produced fruit, used purely as a fruit rather than as processed derivatives, is the mango, of which world production might well exceed 20 million tons. The mango is thus quite definitely one of the most important fruits in the world and perhaps the leading tropical fruit.

In every tropical country I have lived in or visited in both Old and New Worlds, where climate and temperature have been suitable, there mango trees are grown ; in many they are as abundant as any other fruit. The finest mangoes I have eaten were consumed in my bath in Calcutta, the best place for eating a really perfect fruit ; but some Philippine varieties approach closely the best of India. It is therefore a little surprising that so little is included on the extra-Indian range of this fruit tree. The presumption is that relatively little work has been published outside that country.

In India 2·2 million acres, 70% of the total area under fruits, is occupied by mango groves. Dr. L. B. Singh, as Director of the Horticultural Research Institute of Saharanpur, United Provinces, is peculiarly well qualified to write of mango cultivation in India. He covers every aspect of the botany, cultivation and utilization of the mango tree and of its fruit and cites about 7,000 references to literature —much of which he owns to being empiric and of doubtful value. Where truly scientific research has been done he gives it in detail. His chapter on propagation, mainly vegetative, is full and well illustrated. In his chapter on nutrition from the seedling nursery to the mature tree he quotes a selection of the great variety of treatments given and ends with this sentence : " It appears that the study of the problem of mango manuring is still in its infancy, and a more thorough research from several angles is necessary before any definite conclusions can be drawn "—a very fair judgment which reflects the author's cautious approach. One point is made very clear, the need to give plenty of manure at the time of planting and indeed throughout the whole life of the tree. The pre-planting treatment he quotes is generous and implies either that the poverty of the soil is recognized or that empirical knowledge acquired over the centuries has shown that generous treatment pays dividends in yield. Fertilization of bearing trees should be equally heavy and this is appreciated outside India for in Israel it is recommended that a mango tree should get farmyard manure equal to the weight of the fruit plus 80 kg., in addition to chemical fertilizers.

This is the most complete and authoritative work on the mango ; it is well written and fully illustrated and should prove of value wherever the mango is grow from Cancer to Capricorn.

G.A.C.H.

PLANT VIRUSES. By Kenneth M. Smith. 3rd edition, revised 1960. (London : Methuen & Co. Ltd. New York : John Wiley & Sons Inc. Pp. 209, illus. Price 16s. and 6d.)

As did the earlier editions, this book will prove invaluable for the student who has no previous knowledge of plant viruses. The teaching of plant pathology at most universities is such that this will apply almost equally to post- and undergraduates ; it is presumably because so little virology is taught that the demand for a new edition has not been met sooner. So far as the reviewer is aware, this is the only elementary text-book of plant viruses published in English. (The author's *Standard Textbook of Plant Viruses and Virus Diseases* has become the *vade mecum* of both the research worker and the advisory plant pathologist.)

The new edition is more comprehensive than the first and, because of the greatly increased breadth of the subject, it contains twice the number of pages. It consists of two parts, the first dealing with viruses, vectors and plant hosts, the second with

practical methods used in the study of plant viruses. There is also an appended list of " Some common viruses and their indicator plants ", but this is of limited value because only one host is usually given for each ; there are few viruses that can be identified by the symptoms on a single host plant.

Typographical errors are few and unimportant, but at least two errors of fact should not go uncorrected. The " serious disease of raspberry plants in Scotland " is presumably leaf curl and not yellow dwarf. The virus responsible for tristeza disease of citrus is commonly latent in scion varieties and not " in the sour orange rootstock " which is grown from seed.

It was surprising to find no mention of the gel-diffusion precipitation test in the chapter on serology, and no advice on insect transmission tests among the practical methods in plant virology. It must, however, have been difficult to decide what to omit in order to restrict the book to a reasonable size and the author has succeeded in condensing into an easily read text the information most needed by the student.

A.F.P.

MODERN FRUIT SCIENCE. By Norman Childers. 2nd edition. (Horticultural Publications, Rutgers University, Nichol Avenue, New Brunswick, New Jersey, U.S.A. 1961. Pp. 893, illus. Price $7.50.)

This is a new edition of the text-book on fruit growing in the U.S.A., by the same author, which was first published by the J. B. Lippincott Co., Chicago, in 1949. It has proved its value to teachers and students through four reprintings and now the author has taken the opportunity to make some revisions and include new material. He has again had the help of many specialists within the broad field of fruit science and the result is a fully revised and up-to-date text-book that any student of fruit growing might study with profit and be pleased to possess. The book has eight pages of index and 24 pages of widely drawn references to supplement those that follow each chapter. The numerous illustrations lend point to the text. Some, like the series on pp. 229–30, showing the poise of the hands and the sequence of movements in wrapping apples for box packing, and Fig. 20, showing a fruit-laden peach branch before and after thinning, are commendable, but some others (e.g. Fig. 14, apple mineral deficiencies and Fig. 2, life history of the codling moth) would not give the student much help. Too many of the photographic illustrations are poorly reproduced. The contents cover the expected range of subjects : from decision on the sort of enterprise and the choice of locality and site, through the choosing of varieties, propagation, planting and establishment, pruning, soil management, control of growth, pollination problems, biennial bearing, pest and disease control and climatic troubles, to harvesting, storing and marketing. Apples receive the fullest attention as befits this most important crop, and the chapters dealing with the culture of the other tree fruits, pears, quinces, peaches, nectarines, apricots and almonds, plums and cherries are adequate. The growing of berry fruits is also fully described and the chapter on edible nuts emphasizes the commercial importance of these in different regions, notably California and Oregon for walnuts and the Southern States for pecans. Of special interest is the able treatment of orchard spraying. Students may well get good guidance on judging and exhibiting, and teachers in Europe, at any rate, will congratulate Professor Childers on the selection of material for the chapters on harvesting and storing and also on the presentation of economic data throughout the book.

H.W.M.

MODERN INSECTICIDES AND WORLD FOOD PRODUCTION. By F. A. Gunther and L. R. Jeppson. (London: Chapman and Hall. 1960. Pp. 284, illus. Price 50s. net.)

This is a book about insecticides and acaricides, with the need to increase food supplies kept in mind ; it therefore differs markedly in approach from Ordish's *The Untaken Harvest*, and one cannot turn to it for much data concerning crop losses due to pests. On the other hand, as an introduction to economic entomology and to the roles played by suitable chemicals in the control of invertebrate pests, it could hardly be bettered. All the compounds of any significance today are dealt with, using wherever possible the recommended common name or, where one does not exist, the commercial short name ; alternative short names are given, as is also the correct chemical name, but there are *no formulae*.

The use of insecticides is set in perspective, and then various problems associated with their use are considered. These include getting the toxicant to the right sites of action and maintaining it at an effective level for the right time, the effect on the other arthropod members of the environment, the determination of residues present at harvest and their significance, and the major problem now facing economic entomology, namely resistance by insects and mites to chemical control. The scientific names for pests mentioned in the text by common names are given in one appendix, and another gives approximate comparative figures for the mammalian toxicity of over 100 pesticides.

The book is well printed on non-glossy paper, to the present reviewer's delight ; the type used for numerals is, however, not very satisfactory, the figures 3 and 5 being hard to distinguish. Printer's errors are rare.

It is unlikely that this book will be read by the man-in-the-street ; it is too scientific for that. There is, therefore, room for, say, a Penguin to carry the fight against ignorance and fear to the main mass of, at any rate, the British public, who must consume food largely protected by chemicals at some stage or other of its production, storage, transport and marketing.

A.H.M.K.

NOTICE TO CONTRIBUTORS

1. All **manuscripts** should be in double-spaced typewriting, with a good margin, and should be addressed to the Editor, East Malling Research Station, near Maidstone, Kent, England. Papers must be written concisely. Historical reviews should be as short as possible and only such references to literature as bear directly on the subject should be included. Tables and illustrations, if any, must be only such as are absolutely essential for clear presentation.

2. Authors of papers containing extensive **numerical observations** should consult the recommendations of the British Association Committee on Biological Measurements, 1927, obtainable from Burlington House, London, W.1, price 6d. Arrangements have been made whereby original data too extensive for complete publication may be deposited at the British Museum (Natural History), London, S.W.7, or with the Royal Society of Edinburgh, 22 George Street, and thus be available for consultation by other workers. Full bibliographical reference to the publication in which the results are summarized must be supplied with the data.

3. Each paper must conclude with a concise and critically correct **summary** of its actual content. It should contain any new or verified constants as well as any other critical data of permanent value but not tables or graphs. Any organism mentioned should be given its scientific name.

4. Where a paper is of a highly technical nature it should be preceded by a brief **synopsis**, in which its contents are simply and clearly stated for the benefit of non-technical readers.

5. **References to literature** may be by numbers (in brackets) in the text corresponding to a numbered list at the end of the paper or by the Harvard system (author's name and date of publication). By either method, the papers cited should be listed alphabetically according to authors' names, followed by the date of publication. The title of the paper should next be given in full, followed by contracted, but strictly intelligible, title of source of publication, the volume and page numbers. Authors are responsible for the accuracy of their lists of references and should check them carefully in both typescript and proof.

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